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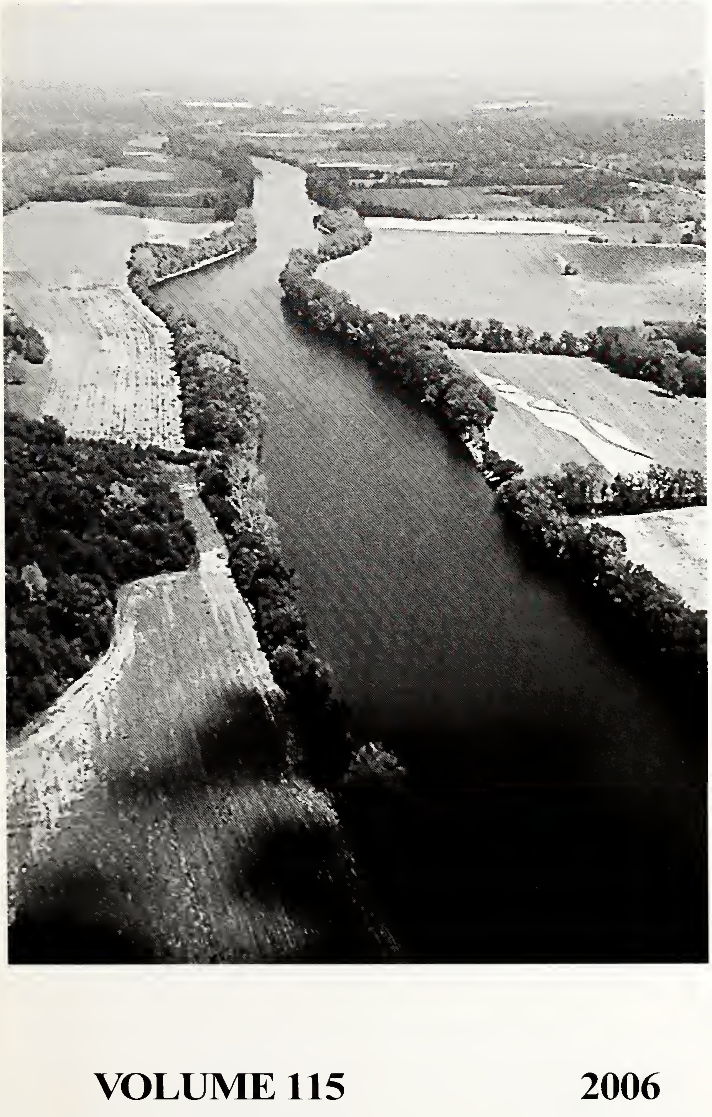

A Series of Papers from the Wabash River Symposium

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Cover photo: The Wabash River drains an area of 32,910 square miles, including about 8,704 square miles in Illinois and another 285 square miles in northwestern Ohio. It drains central and southern Indiana and flows in a southwesterly direction. Its upper watershed consists primarily of ground moraine and end moraines deposited during the Wisconsinan glaciation. The greatest elevation within the basin is 366 m and the lowest at the mouth is about 92 m above sea level. The surrounding topography is nearly flat to gently rolling and has gentle land slopes except downstream, where entrenchment of the river valley is greatest. (Photo by Jim Gammon)

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THE WABASH RIVER SYMPOSIUM

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Important in both the natural and cultural history of the region, the Wabash River is considered The River of Indiana, and it is the designated State River. From its origin in the state of Ohio to its junction with the Ohio River, the Wabash runs 765 km. From the dam in Huntington, Indiana to its terminus at the Ohio River, the Wabash flows freely for 661 km of its total length, the longest stretch of free-flowing river in the United States east of the Mississippi River (Fig. 1). Several papers in this issue of the *Proceedings* of the Indiana Academy of Science are devoted to aspects of the biodiversity, environment, and conservation of the Wabash River drainage. This series of papers developed from a symposium on the Wabash River held in conjunction with the 2005 annual meeting of the Academy. The following introduction will provide a brief overview of the Wabash River, the 2005 symposium, and the Wabash River section of this issue of the *Proceedings*.

The Wabash River basin is comprised of a series of 12 watersheds that were designated by the State of Indiana in 1956 (Clark 1980). The Wabash River drains an area of 32,910 square miles (85,560 sq. km), including about 8,704 square miles in Illinois and another 285 square miles in northwestern Ohio. The Wabash River crosses two ecoregions and is the largest drainage in Indiana (Omernik & Gallant 1988). The principal tributary is the White River, which drains the Eastern Corn Belt Plain and the Interior River Lowland. The Wabash River drains central and southern Indiana and flows in a southwestly direction. The mainstem Wabash River is the principal drainage of the Interior River Lowland.

The population of the Wabash River basin, within the State of Indiana, included approximately 3.56 million people in 2000 (U.S. Census Bureau, http://quickfacts.census.gov/qfd/states/18000.html). This represents 58.9% of the entire population of Indiana. The economy of the basin is primarily agriculture; but manufacturing is of significant importance. Land use in the Wabash River is primarily agricultural (66%); however, significant portions in the southern watershed are comprised of forest (15%), and urban land uses (13%) (Purdue University, http://pasture.ecn.purdue.edu/~jychoi/wd_home/).

The upper Wabash River consists primarily of ground moraine and end moraines deposited during the Wisconsinan glaciation (Fenneman 1946; Schneider 1966). The upper Wabash includes areas covered by the Packerton Moraine, which is within the Northern Lake and Moraine region, while the remaining area is in the Tipton Till Plain (Wayne 1956). The topography is nearly flat to gently rolling and has gentle land slopes except near the downstream reach of the Wabash River, where entrenchment of the river valley is greatest. The Wisconsinan glaciation event and other consolidated deposits in Indiana did not fully cover the lower Wabash River (Fenneman 1946). Thus, these areas may have been refugia for species pushed south by the glacier. Deposits from the Illinoian and older glaciation events were more discontinuous. As many as eight or nine distinct till sheets overlap in western Indiana. Elevation within the basin is greatest in Randolph County, which is slightly more than 366 m and lowest at the mouth of the Wabash

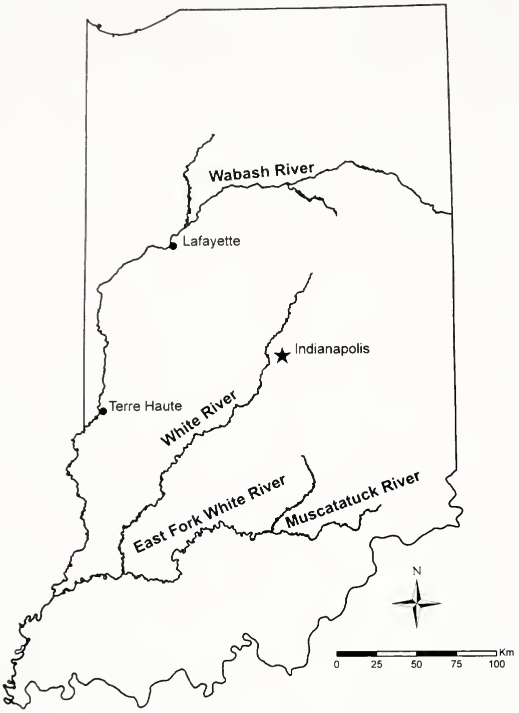

Figure 1.—The Wabash River Basin, draining portions of Illinois, Indiana, and Ohio. (Map by Peter A. Worcester, Geology Department, Hanover College)

River which is about 92 m above mean sea level.

Average annual precipitation is about 110 cm with an average monthly value ranging from a high in March and a low in October (Clark 1980). About 65% of the annual precipitation is used through evapotranspiration, while 34.8% comprises stream flow. The long-term average temperatures range from 0 °C in January to 25 °C in July. The average annual temperature is 14 °C. The average precipitation ranges from 92–112 cm from north to south. The average annual snowfall ranges from 178 cm to 41 cm from north to south. Snowfall contributes between 5–18 cm of average annual precipitation.

Soils in the Wabash River basin include clay glacial till soils in the upper Wabash, loamy glacial tills to moderately thick loess over loamy glacial till in the central watershed, and discontinuous loess over weathered sandstone and shale in the lower watershed (Clark 1980). The topography of the Wabash River ranges from a plain of mostly clay till interspersed with looping belts of rolling, hummocky ridged morainic upland to rolling plains underlain by loess, till, and bedrock with broad valley flats underlain by thick deposits of alluvium, outwash, and lake deposits (Schneider 1966).

The Wabash River was well-known for its abundant fish during the early 1800s, but declines occurred through a combination of increased agriculture, manufacturing activities, and urban impacts in the watershed. These events culminated in multiple fish kills during the 1970s (Gammon 1998). Reduced point-source pollutants and increasing awareness of non-point source agricultural run-off have improved water quality, although excessive nutrients appear to contribute to summer algal blooms and decreased water clarity. These improvements were likely in response to legislation including the Clean Water Act of 1972 (www.epa.gov) and Payment-In-Kind (PIK) in 1983 (Gammon 2005). The PIK program reduced agricultural loadings of nutrients to the river by 25% (Gammon 1998). Today numerous conservation and political organizations in the State of Indiana, including The Wabash River Heritage Corridor Commission, the Wabash Riverkeepers, and The Nature Conservancy, work to protect and preserve the natural and cultural heritage of the Wabash River.

The Wabash River was the focus of a special program at the Fall Meeting of the Indiana Academy of Science (held on 6–7 October 2005 at St. Mary of-the-Woods College near Terre Haute, Indiana). The Wabash River Symposium was planned and organized by the Biodiversity and Natural Areas Committee of IAS and the Rivers Institute at Hanover College.

The Wabash River Symposium included several components. On October 6, the Rivers Institute hosted a reception and dinner. Dinner was followed with a keynote address by Dr. James Gammon of DePauw University. Dr. Gammon began working on the Wabash River in the 1960s. The title of Dr. Gammon's talk was "A Wabash River Overview—Past, Present and Future." He provided a personal reflection on 40 years of research on the river. Dr. Gammon is the subject of a biographical article in this issue of the *Proceedings*. The Symposium continued on the morning of 7 October with a special session of ten presentations regarding the biodiversity and conservation of the Wabash River. Topics covered fish and mussels of the Wabash (T. Simon, M. Pyron and B. Fisher), small mammals of the Wabash Valley (J. Whitaker, Jr.), plant communities of the Wabash Valley (M. Jackson and M. Homoya), environmental quality of the Wabash River (L. Bridges and S. Sobat), and conservation issues (R. Schnapp and R. James). Research and review articles based on some of the Wabash Symposium presentations plus several invited articles on related aspects of the Wabash environment appear in this issue of the *Proceedings*.

On the afternoon of 7 October, 35 scientists and volunteer naturalists, including a number of the Wabash session presenters, took part in a short-term "BioBlitz" on Otter Creek, a tributary of the Wabash River in Vigo County. A BioBlitz is a rapid assessment of the biodiversity of a specific site by taxonomic experts. A full BioBlitz lasts for 24 hours and may involve hundreds of participants; this event took place on one afternoon with a smaller number of participants. The BioBlitz participants split into aquatic, terrestrial plant, and terrestrial animal teams. The results of the Otter Creek BioBlitz are reported in this issue and are posted on the Academy website.

ACKNOWLEDGMENTS

We would like to thank the Biodiversity and Natural Areas Committee of the Indiana Academy of Science and the Rivers Institute of Hanover College for support of the Wabash River Symposium. One component of the mission of the Biodiversity and Natural Areas Committee of the IAS is to disseminate information about and to help preserve the biological diversity of the state. The Rivers Institute, created in 2004 through a grant from the Lilly Endowment, is devoted to the interdisciplinary and collaborative study of river systems using the disciplines of the liberal arts. We also thank the faculty and staff of St. Mary of-the-Woods College for their generous cooperation in planning the Wabash River Symposium and for hosting the 2005 annual meeting of the Indiana Academy of Science. We especially thank all the individuals who either participated in the Wabash River Symposium or contributed papers to this volume.

LITERATURE CITED

Clark, G.D. (ed). 1980. The Indiana Water Resource: Availability, Uses, and Needs. State of Indiana, Water Resource Study Commission, Indianapolis, Indiana.

Fenneman, N.M. 1946. Physical divisions of the United States. U.S. Geological Survey Special Map, Washington, D.C.

Gammon J.R. 1998. The Wabash River Ecosystem. Indiana University Press, Bloomington, Indiana.

Gammon, J.R. 2005. Wabash River fishes from 1800 to 2000. Pp. 365–381, *In* Historical Changes in Large River Fish Assemblages of the Americas. (J.N. Rinne et al., eds.). American Fisheries Society, Bethesda, Maryland.

Omernik, J.M. & A.L. Gallant. 1988. Ecoregions of the upper midwest States. EPA 600/3-88/037. U.S. Environmental Protection Agency, Pacific Ecology Laboratory, Corvallis, Oregon.

Purdue University. 2004. Watershed delineation/ watershed generation. http://pasture.ecn.purdue.edu/~jychoi/wd_home/). West Lafayette, Indiana.

Schneider, A.F. 1966. Physiography. Pp. 40–56, *In* Natural Features of Indiana. (A.A. Lindsey, ed.). University of Notre Dame Press, South Bend, Indiana.

U.S. Census Bureau. 2006. State of Indiana Quick facts. http://quickfacts.census.gov/qfd/states/18000.html. U.S. Census Bureau, Washington, D.C.

Wayne, W.J. 1956. Thickness of drift and bedrock physiography of Indiana north of the Wisconsin glacial boundary. Indiana Department of Conservation, Geological Survey Program Report 7. 70 pp.

Manuscript received 22 September 2006.

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RESULTS OF A SHORT-TERM BIOBLITZ OF THE AQUATIC AND TERRESTRIAL HABITATS OF OTTER CREEK, VIGO COUNTY, INDIANA

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ABSTRACT. A short-term (approximately three hours) BioBlitz (rapid assessment of the species living in a particular area at one time) was conducted in the vicinity of Otter Creek, a tributary of the Wabash River in Vigo County, Indiana on 7 October 2005. A total of 35 scientists and naturalists divided into aquatic, terrestrial animal, and terrestrial plant teams to survey different taxonomic groups. The teams recorded a total of 370 species: 205 plant species, 43 fungus, 9 insect, 8 bivalve, 2 crayfish, 52 fish, 6 amphibian, 34 bird, and 11 mammal species (with some additional aquatic and mammal sampling outside the three-hour period). Species found were representative of the lower Wabash River drainage. BioBlitz events vary in scientific value, but can provide valuable scientific information as well as serve as a vehicle for public education about the natural world and conservation issues. We compare the results of the Otter Creek survey to other BioBlitz events in the Midwest.

Keywords: BioBlitz, biodiversity, Vigo County, Indiana

A BioBlitz, short for Biodiversity Blitz, is a rapid assessment of the species living in a particular area at a given point in time and is usually conducted over a 24-hour period. To complete a successful BioBlitz, the natural history talents of scientists and naturalists in an area (or state) are recruited to document the biodiversity present (Lundmark 2003). A one-day event can only begin to document all the species present in an area. Because the species assemblage changes throughout the year, species will inevitably be missed. However, the BioBlitz gives a "snapshot in time" of the species present in a particular area.

The BioBlitz concept is an outgrowth of formal biodiversity survey programs, such as the Rapid Assessment Program (RAP) of Conservation International and the BIOTROP program of the Neotropical Biological Diversity Program at the University of Kansas (Wilson 1992), generated by growing awareness and concern for biological diversity. The first BioBlitz took place in May, 1996 in Kenilworth Park and the Aquatic Gardens National Park, Washington D.C. (Post 2003; Droege 2006). Since that event, the BioBlitz concept has been adopted by numerous government agencies and private groups. Post (2003) notes that, as of 2003, there have been 58 BioBlitzes held in 25 states, with an additional 15 in six other countries. The number of events has grown steadily. Some BioBlitzes have become ongoing, annual or semi-annual events (e.g., Minnesota and Connecticut BioBlitz events sponsored by the Bell Museum of Natural History, University of Minnesota and the Connecticut Museum of Natural History, University of Connecticut; Bell Museum 2006;

University of Connecticut 2006). A wide variety of localities have been sampled, from relatively undisturbed, protected areas to heavily developed urban landscapes.

When the concept of biodiversity [the variety of living things] is mentioned, most people tend to think of tropical rainforests or coral reefs (Conniff 2000), not a Midwestern farm state in the United States. However, Indiana exhibits considerable biological diversity across the state, both east to west and north to south. Despite over two centuries of research, the distribution, occurrence, and patterns of plant and animal species nowhere on this planet, including Indiana, are completely documented.

On 7 October 2005, the Rivers Institute at Hanover College in collaboration with the Biodiversity and Natural Areas Committee of the Indiana Academy of Sciences (IAS) hosted a short-term BioBlitz on Otter Creek, a tributary of the Wabash River, in Terre Haute, Indiana. The BioBlitz was held in conjunction with the 2005 symposium on the Wabash River that is featured in this issue of the *Proceedings* of the Indiana Academy of Science. The event was short-term because it occurred primarily within a three-hour time-block following the annual meeting of the Academy. Because of the short duration of the event, less emphasis was placed on species inventory, that is, voucher specimens were not collected. This paper reports the diversity of life recorded during the Otter Creek BioBlitz, compares the results of this BioBlitz to other Midwest BioBlitz events, and discusses the value of the BioBlitz concept.

METHODS

The short-term BioBlitz focused on both the aquatic species of Otter Creek and the terrestrial species associated with habitats adjacent to the creek. Participating scientists and volunteer naturalists were divided into three teams: the aquatic group, the terrestrial animal group, and the terrestrial plant group. The majority of sampling effort occurred from 1400–1700 h on 7 October 2005. In addition, the fish, crayfish, and mussel group sampled in the morning and the afternoon of 7 October, and the mammal group deployed live and snap-traps on the night of 6–7 October. Weather conditions were sunny and dry with air temperatures between 22–25 °C during the three-hour event on 7 October.

Aquatic survey methods.—The aquatic group consisted of three observers led by Thomas P. Simon, U.S. Fish and Wildlife Service, and Brant E. Fisher, Indiana Department of Natural Resources. They collected fish, mussels and clams, and crayfish in Otter Creek, a tributary of the Wabash, at two locations in Vigo County: 1) the U.S. 41 bridge (upstream and downstream about 300 m) in Fayette Township, approximately 5 km north of the Terre Haute Township limits on U.S. 41 (39°33′22″ N, 87°23′36″ W), 2) the Markles Mill Dam (downstream about 150 m) in Markles Mill Park, Otter Creek Township, approximately 1 km northeast of the Terre Haute Township limits (39°31′40″ N, 87°20′46″ W). Sampling was done at the U.S. 41 site in the morning and at Markles Mill Park in the afternoon. In addition, Ronald A. Hellenthal (Notre Dame University) and volunteers sampled aquatic macroinvertebrates at Markles Mill Park, but that species report is not included here.

Fish, crayfish, and mussel assemblages were collected during daytime inventories. Sampling included distances of 150 m or about 35 times mean stream width, and sampling was conducted for 1800 sec in each zone. This distance is the equivalent of two habitat cycles (Leopold et al. 1964). In larger segments, two riffle-pool/run series were collected. All habitats in the stream reach were sampled relative to their abundance. Fish and crayfish were collected using a Smith-Root Model 12-B® battery-powered backpack electrofishing unit, while mussels were collected by sight observation while wading through the zone. No crayfish burrows were observed in either zone, possibly because of the late date of collection.

Field collections of fish and crayfish were identified in the field using standard taxonomic references (Smith 1979; Etnier & Starnes 1993). Only two crayfish were preserved in 70% ethanol and verified in the laboratory using standard taxonomic references (Page 1985). Mussels were ranked as live, fresh dead, or fossil based on shell characteristics. Any anomalies present on fish such as deformities, eroded fins, lesions, and tumors (DELTs) were noted.

Terrestrial survey methods.—Both the terrestrial plant and animal groups worked in Forest Park (39°31′28″ N, 87°20′32″ W), a private park owned by First Financial Bank, Terre Haute, located immediately south of the Markles Mill Park. Forest Park is a 154 ha mosaic of mowed parkland, second-growth forest, and old fields; an approximately 1 ha pond is on the property. Otter Creek runs through the park.

The terrestrial plant group consisted of 15 observers led by Marion T. Jackson, Indiana State University, and Paul E. Rothrock, Taylor University. Their survey included a range of local community types such as mature hardwood forest, wooded ravines, swamp woods, woodland ecotones, mowed turf, early successional disturbance areas, and pond margins. The fungus group consisted of three collectors led by Donald G. Ruch, Ball State University. They surveyed in mixed deciduous forest. Both the plant and fungus groups made field identifications and also collected some taxa for later identification. For vascular plants, nomenclature and species concepts followed that of Rothrock (2004).

The terrestrial insect group consisted of one observer, Robert Jean, Indiana State University. He searched in upland second growth forest (some areas of old growth), lawn pastures, around the pond, and in the floodplain near Otter Creek.

The amphibian and reptile group consisted of four observers led by Robert D. Brodman, St. Joseph's College. They searched deciduous forest edge and interior, the pond and shoreline, the edges of Otter Creek, and open parkland by overturning rock and wood cover objects and debris. They recorded four amphibian species; the aquatic team recorded two additional species in Otter Creek. The nomenclatural authority used for amphibians and reptiles was Crother et al. (2001).

The bird group consisted of six observers led by Peter Scott, Indiana State University. They searched upland deciduous forest edges and interior (70% of survey time), a pond (~1 ha in size) and its shoreline (5% of time), and early successional shrubs and herbs in a power line corridor within the forest (25% of time). The nomenclatural authority used for birds was Banks et al. (2003).

The mammal group consisted of three observers led by John O. Whitaker, Jr., Indiana State University. They deployed 450 snap-traps and 50 live traps for one night (6–7 October; 500 trap-nights). They trapped in weedy, grassy areas along a mowed field, along Otter Creek, and in a cornfield. They also made visual and aural observations during the trapping and collecting period. The nomenclatural authority used for mammals was Mumford & Whitaker (1982).

RESULTS AND DISCUSSION

The biological diversity recorded by 35 observers within a three-hour time block (with some additional effort for mammals and aquatic species) on the afternoon of 7 October 2005 was 370 species: 205 plant species (4 phyla), 43 fungus species (2 phyla), 9 insect species (5 families), 8 bivalve species (2 families), 2 crayfish species (1 family), 52 fish species (9 families), 6 amphibian species (4 families), 34 bird species (21 families), and 11 mammal species (7 families). Due to space considerations, a summary table with the number of species listed by phyla (plants and fungi) and by class and family (all other taxa) is provided here (Table 1). A complete listing of the species observed is posted on the Indiana Academy website (http://www.indianaacademyofscience.org/), available through the Biodiversity and Natural Areas Committee of the Academy, and from the first author. None of the survey groups recorded species that were new records for the geographic area or that are listed as federally or state endangered. Species recorded were representative of the taxa expected to be found in a suburban/rural mosaic of forest patches, residential areas, and agricultural land use in the lower Wabash River drainage in southwestern Indiana.

Of the 205 plant species observed during the short-term BioBlitz, 173, or 84.4%, were native and 32, or 15.6%, were non-native. Using the floristic quality assessment program (Wilhelm & Masters 1999; Rothrock 2004), the following information was generated: Floristic Quality Index (FQI) for native species only is 48.4, while the FQI for all species is 44.5,and the mean C (e.g., Coefficient of Conservatism) for only the native plants is 3.7, while for all plant species, the mean C = 3.1. These numbers suggest that the area of Forest Park appraised contains some remnants of the region's natural heritage. Nevertheless, because the difference between the native mean

Table 1.—Summary list of the number of terrestrial and aquatic species identified during the short-term BioBlitz, Otter Creek, Vigo County, Indiana. Species numbers are listed by phyla (plants and fungi) and by class and family (all other taxa). See text for details regarding collection location and methods.

Taxon (Common name)	Number of species
Plants	
Equisetophyta (horestails)	2
Polypodiophyta (ferns)	6
Coniferophyta (conifers)	1
Magnoliophyta (angiosperms)	
native	164
non-native	32
Fungi	
Ascomycota (sac fungi)	3
Basidiomycota (club fungi)	40
Insects	
Apidae (bumble bees, honey bees & allies)	2
Nymphalidae (brush-footed butterflies)	3
Lycaenidae (gossamer-winged butterflies)	1
Pieridae (whites, sulfurs & allies)	1
Acrididae (short-horned grasshoppers)	2
Crustaceans	
Cambaridae (crayfish)	2
Bivalves	
Unionidae (unionid mussls)	7
Corbiculidae (Asian clams)	1
Fish	
Clupeidae (herrings)	1
Cyprinidae (minnows)	19
Catostomidae (suckers)	7
Ictaluridae (catfish)	4
Fundulidae (topminnows)	1
Moronidae (temperate basses)	1
Centrarchidae (black basses & sunfish)	10
Percidae (perch & darters)	9
Sciaenidae (freshwater drums)	1
Amphibians	
Proteidae (mudpuppies)	1
Plethodontidae (lungless salamanders)	3
Hylidae (treefrogs)	1
Ranidae (frogs)	1
Birds	
Anatidae (swans, geese, & ducks)	1
Phasianidae (upland game birds)	1
Ardeidae (wading birds)	1
Cathartidae (New World vultures)	1
Accipitridae (diurnal raptors)	1
Strigidae (owls)	2
Apodidae (swifts)	1
Picidae (woodpeckers)	4
Tyrannidae (tyrant flycatchers)	1
Corvidae (jays & crows)	2
Paridae (titmice & chickadees)	1
Sittidae (nuthatches)	1
Troglodytidae (wrens)	2
Regulidae (kinglets)	2
Turdidae (thrushes)	1
Bombycillidae (waxwings)	1
Parulidae (wood-warblers)	3
Emberizidae (sparrows)	3
Cardinalidae (cardinals & allies)	2
Icteridae (icterids)	1
Fringillidae (finches)	1
Mammals	
Talpidae (moles)	1
Soricidae (shrews)	1
Leporidae (rabbits)	1
Sciuridae (squirrels)	3
Cricetidae (mice & voles)	3
Procyonidae (raccoons)	1
Cervidae (deer)	1
Total	370

C and the mean C for all species is greater than 0.5, this suggests that the natural flora has been compromised by the non-native species (Swink & Wilhelm 1994; Rothrock & Homoya 2005). However, due to the short duration and single-season sample of the Otter Creek BioBlitz, these numbers should be interpreted with caution.

A total of 40 species of fish was recorded from the Highway 41 site and 44 species from the Markles Mill Dam site, for a total of 52 different fish species from the combined sites. The Markles Mill Dam site is notable for its stability in physical characteristics over the last 180 years and its high species diversity (Whitaker 1976). Whitaker (1976) reported the composition of the fish assemblage collected at the Markles Mill Dam over a 12-year (28 collections) period; a total of 57 fish species was recorded. This data set has been analyzed multiple times in a series of papers dealing with theoretical aspects of community structure (e.g., Grossman et al. 1985). It is noteworthy that the BioBlitz reported here recorded 44 species from Markles Mill Dam in a one-day sampling period, compared to 57 species over a 12-year period.

The number of species recorded during a BioBlitz is dependent on a number of variables, such as seasonality, weather conditions preceding and during the survey, the number and type of wetlands on the site, the number of collectors, and taxonomic expertise of the collectors. We sampled during the day, in early fall, with dry weather conditions. For this reason, it is not surprising that we recorded only six species of amphibians. Four of the species were found in the vicinity of a forested ravine with a small stream, and the other two were collected by the aquatic team in Otter Creek. Alternatively, depending on moisture levels, fall is a good time for locating fungus species, and 43 species were recorded. A full BioBlitz typically lasts 24 hours (although some run longer), and nocturnal species would have been observed that we did not record. Our survey groups were strongly biased toward plants (15 of 35 collectors) and vertebrates (15 of 35 collectors). Invertebrates, especially insects, are clearly underrepresented in the survey, and more expertise with invertebrates would have added a significant number of species to the inventory.

Other Midwestern U.S. BioBlitzes have been conducted that provide a basis of comparison among regional BioBlitz events. The Allerton BioBlitz (the first BioBlitz in Illinois) was conducted on 29–30 June 2001 at Robert Allerton Park near Monticello, Illinois in Piatt County. The Calumet BioBlitz was conducted on 23–24 August 2002 on the southeast side of Chicago in Cook County, Illinois and in adjacent Hammond in Lake County, Indiana (Parker 2002; Post 2003). These BioBlitz events were sponsored by several government and private agencies. At the Allerton BioBlitz, over 160 scientists recorded 2047 species in 24 hours from a protected natural area. At the Calumet BioBlitz, over 130 scientists, divided into 26 taxonomic teams, recorded a total of 2257 species in the 24-hour collecting period, despite the fact that the general area of the BioBlitz has been the location of major industrial activities for over a century.

The Bell Museum of Natural History, University of Minnesota, has organized a smaller scale BioBlitz since 2004 (Bell Museum 2006). On 19–20 May 2006, over a 24-hour period, 40 researchers and experienced volunteers (similar in number to our short-term BioBlitz) sampled an area that included a city neighborhood, farm fields, a university campus, suburban housing, and a golf course. They recorded a total of 876 species (456 plant species, 54 fungus, 78 mammal, 232 insect, 2 fish, 2 reptile, 3 amphibian, 18 spider, 3 mollusk, and 8 other invertebrate species). In 2004 they recorded 750 species over a 24-hour period at a nature center and just under 1000 species in 2005 at the Minnesota National Wildlife Refuge over a 24-hour period.

We have assembled an inventory of BioBlitz events held in Indiana. We recognize that this may not be a complete list due to the manner in which BioBlitz events are often reported (via news media outlets and websites). The 2002 Calumet BioBlitz took place in both Illinois and Indiana and, to the best of our knowledge, was the first BioBlitz held in Indiana. The second BioBlitz held in Indiana was conducted on 17 April 2004 at Camp Lawrence, a 139-acre children's summer camp in Porter County. There were 17 biologists, naturalists, and volunteer participants involved and over 300 visitors (Alan Resetar, Field Museum, personal communication). A total of 366 species (including 8 fish species, 8 amphibian and reptile, 44 bird, 9 mammal, and 189 plant species) was recorded in seven hours. The 2005 Otter Creek short-term BioBlitz reported here is the third BioBlitz held in Indiana. A fourth BioBlitz was conducted by ACRES land trust at the Kokiwanee Nature Preserve in Wabash County in northeastern Indiana on 9–10 June 2006; the event was a full 24-hour BioBlitz with at least 10 scientists (Kimmel 2006). Three short-term BioBlitzes, hosted by the Purdue University Cooperative Extension Service and the Floyd County Soil and Water Conservation District, were held at Loop Islands Wetlands, New Albany (20 July 2006), Charlestown State Park, Charlestown (27 July 2006), and the Mount Saint Francis Wildlife Sanctuary, Floyd Knobs (10 August 2006) in southern Indiana. A six-hour BioBlitz was held 23 September 2005 at St. Patrick's County Park in South Bend, Indiana. Thus, we have been able to identify eight BioBltiz events of variable scope that took place in Indiana between 2001 and 2006.

BioBlitzes vary widely in the number of participants, taxonomic expertise, duration, and size of the area surveyed. Details of the BioBlitz (number collectors, species list) are sometimes not easily available. However, a crude comparison can be made by dividing the total number of species observed by the number of person-hours invested (number collectors times number of hours), when this information can be obtained. We calculated that the Otter Creek, 2005 BioBlitz (370 species, 35 collectors, 3 hours) recorded 3.5 species per collector/hour; Camp Lawrence 2004 (366, 17, 7): 3.1; Minnesota 2006 (876, 40, 24): 0.9; Calumet 2002 (2257, 130, 24): 0.7; and Allerton Park 2001 (2047, 160, 24): 0.3. Thus, not surprisingly, the 24-hour BioBlitzes record more species than short-term BioBlitz events, but the number of species per collector-hour is lower. Considering the short duration and lack of taxonomic coverage of the Otter Creek short-term BioBlitz, the total of 370 species recorded is somewhat surprising and impressive.

The scientific usefulness of BioBlitz events varies considerably; some are conducted as formal, intensive surveys with the participation of many taxonomic specialists and qualified naturalists (e.g., Calumet BioBlitz, the BioBlitz reported here), others are primarily public education events in which the quality of the scientific results of the survey is not as important as the educational experience provided. BioBlitzes cannot provide a complete species inventory nor be used as the basis of a formal monitoring program. However; they can provide valuable scientific information through documentation of species occurrences (Droege 2006; Lundmark 2006). For example, BioBlitzes can identify sites where rare or unique native species are found, identify invasive species (as done in this report) that may need to be monitored or controlled, and they can jumpstart a more complete species inventory of an area. BioBlitz events bring together specialists from diverse disciplines that might not normally interact and may result in synergy among disciplines and agencies.

Just as important, a BioBlitz event provides a valuable service of public education that attracts non-specialists and allows them to interact with the scientific community in ways that might not otherwise be possible. Children, in particular, find BioBlitzes exciting, which can generate much needed interest in science. BioBlitzes can generate considerable media attention and help increase general awareness about the natural world and generate interest in conservation issues (Droege 2006). The Biodiversity and Natural Areas Committee of the Indiana Academy of Sciences is investigating the development of a BioBlitz program for the State of Indiana.

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LITERATURE CITED

Banks, R.C., C. Cicero, J.L. Dunn, A.W. Kratter, P.C. Rasmussen, J.V. Remsen, Jr., J.D. Rising & D.F. Stotz. 2003. Forty-fourth supplement to the American Ornithologists' Union Checklist of North American Birds. The Auk 120:923–931.

Bell Museum of Natural History: Minnesota BioBlitz. Accessed July, 9, 2006. ⟨http://www.bellmuseum.org/bioblitz/⟩.

University of Connecticut: BioBlitz. Accessed 7 July 2006. ⟨http://web.uconn.edu/mnh/bioblitz/⟩.

Conniff, R. 2000. Wanted, dead or alive. Smithsonian 31(1):21–24.

Crother, B.I. 2001. Scientific and standard names of amphibians and reptiles of North America north of Mexico, with comments regarding confidence in our understanding. Society for the Study of Amphibians and Reptiles. Herpetological Circular No. 29. 82 pp.

Droege, S. BioBlitz: A tool for biodiversity exploration, education, and investigation. Accessed 7 July 2006. ⟨http://www.pwrc.usgs.gov/blitz/⟩.

Etnier, D.A. & W.C. Starnes. 1993. The Fishes of Tennessee. The University of Tennessee Press, Knoxville, Tennessee. 704 pp.

Grossman, G.D., M.C. Freeman, P.B. Moyle, & J.O. Whitaker, Jr. 1985. Stochasticity and assemblage characteristics in an Indiana stream fish assemblage. American Naturalist 126(2):275–285.

Kimmel, T. 2006. The ACRES Quarterly 45(3):4–5.

Leopold, L.B., M.G. Woolman, & J.P. Miller. 1964. Fluvial Processes in Geomorphology. W.H. Freeman, San Francisco, California. 535 pp.

Lundmark, C. 2003. BioBlitz: Getting into backyard biodiversity. Bioscience 53(4):329.

Mumford, R.E. & J.O. Whitaker, Jr. 1982. Mammals of Indiana. Indiana University Press, Bloomington, Indiana. 537 pp.

Page, L.M. 1985. The crayfishes and shrimps of Illinois. Bulletin Illinois Natural History Survey 33(4):335–448.

Parker, D. 2002. Calumet BioBlitz. Chicago Wilderness Magazine 4(1):10–13.

Post, S.L. 2003. Biodiversity Blitz: A Day in the Life of . . . The Illinois Steward 12(1):1–8.

Rothrock, P.E. 2004. Floristic quality assessment in Indiana: The concept, use, and development of coefficients of conservatism. Final report for ARN A305-4-53, EPA Wetland Program Development Grant CD975586-01. Available at http://www.in.gov/idem/water/planbr/401/publications.html.

Rothrock, P.E. & M.A. Homoya. 2005. An evaluation of Indiana's floristic quality assessment. Proceedings of the Indiana Academy of Science 114:9–18.

Smith, P.W. 1979. The Fishes of Illinois. University of Illinois Press, Champaign, Illinois. 352 pp.

Swink, F. & G. Wilhelm. 1994. Plants of the Chicago region. 4th edition. Indiana Academy of Science, Indianapolis, Indiana. 921 pp.

Whitaker, J. 1976. Fish community changes at one Vigo County, Indiana locality over a twelve year period. Proceedings of the Indiana Academy of Science 85:191–207.

Wilhelm, G. & L. Masters. 1999. Floristic quality assessment computer program version 1.0. Conservation Research Institute, 324 New York Street, Elmhurst, Illinois 60126.

Wilson, E.O. 1992. The Diversity of Life. Belknap Press of Harvard University Press. Cambridge, Massachusetts. 424 pp.

Manuscript received 8 September 2006.

2006. Proceedings of the Indiana Academy of Science 115(2):89–93

A BRIEF SURVEY OF THE RARE TERRESTRIAL NATURAL COMMUNITIES AND ASSOCIATED VASCULAR FLORA OF THE WABASH RIVER CORRIDOR IN INDIANA

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ABSTRACT. Along the Wabash River corridor in Indiana there exists an array of rare terrestrial natural communities that includes such diverse examples as cliffs, seepage wetlands, prairies, flatwoods, and bald cypress swamps. Many examples are quite small, existing either naturally in small patches, or as remnants of a formerly more extensive occurrence. Many possess rare species, including several that in Indiana are mostly confined to the corridor. Examples include Tennessee milk-vetch (*Astragalus tennesseensis*), water locust (*Gleditsia aquatica*), Amazon sprangletop (*Leptochloa panicoides*), Lesquereux's mustard (*Lesquerella globosa*), cylindric-fruited seedbox (*Ludwigia glandulosa*), plains muhlenbergia (*Muhlenbergia cuspidata*), glade mallow (*Napaea dioica*), Canada burnet (*Sanguisorba canadensis*), Forbes' saxifrage (*Saxifraga forbesii*), and woodland pinkroot (*Spigelia marilandica*).

Keywords: Wabash River, Indiana rare vascular plants, Indiana rare natural communities

Along its course through Indiana the Wabash River flows through a diversity of natural communities that is considerable for such a relatively short run. The context for these communities is the natural regions through which the river flows, *viz.*, the Central Till Plain, Southwestern Lowlands, and Southern Bottomlands (Homoya et al. 1985). Other than the dissected topography created by the entrenchment of the river and its tributaries, the general area within these natural regions is relatively level. The landforms are a consequence of glacial activity, with ice having occupied almost all of the terrain except that within the last few miles of the current river's course (Gray 2000). The glacial landforms, along with bedrock exposure, climate, and environmental perturbations such as fire, have helped to mold the vegetation found in the Wabash River corridor.

This paper addresses those rare natural communities along the Wabash River corridor that were formerly common, e.g., tallgrass prairie, or always rare and localized, e.g., limestone cliff. [The corridor, as defined here, includes that area generally within 3 km horizontally perpendicular to the edge of the river's floodplain]. The order of discussion starts with the natural regions and rare communities in the upper portion of the Wabash River corridor, and ends at the river's confluence with the Ohio River. A partial list of associated rare flora is also provided, including (but not restricted to) species confined in Indiana mostly to the corridor. Emphasis is also placed on species occurring as disjuncts and those at the edge of their range.

METHODS

Most of the communities and species reported herein have been directly observed by members of the Division of Nature Preserves and subsequently documented and stored in the database and files of the Indiana Natural Heritage Program (2006). The number of extant occurrences statewide determines the state rarity categories of plants. These are state endangered (SE), with 1–5 known occurrences in the state; state threatened (ST), with 6–10 known occurrences in the state; and state rare (SR), with 11–20 known occurrences in the state. Additional information on many of these is discussed in Aldrich et al. (1986), Homoya (1983, 1988); Homoya & Abrell (1986); Homoya et al. (1995). Most sites indicated in the text as nature preserves are owned and managed (and/or dedicated) by the Indiana Department of Natural Resources, Division of Nature Preserves.

Nomenclature for most species follows

Gleason & Cronquist (1991). Authority names are given for exceptions.

RESULTS AND DISCUSSION

Central Till Plain Natural Region.—Of all of the natural regions through which the Wabash River flows, its course runs the longest through the Central Till Plain Natural Region and its sections. Here it flows through, in sequential order, the Bluffton Till Plain Section, the Tipton Till Plain Section, and the Entrenched Valley Section. In Indiana it starts at the state line with Ohio and continues within the region to just north of Terre Haute. The following are rare natural communities and vascular plants of the Wabash River corridor in the Central Till Plain Natural Region.

Limestone outcrop: Within the Bluffton Till Plain is a stretch of the river, primarily from Wabash County to Cass County, that possesses a series of outcrops of Silurian limestone (and dolomite). Although small, these outcrops, occurring as cliffs and rocky slopes, provide a naturally exposed bedrock substrate that is exceptionally uncommon for northeastern Indiana. They are host to several plant species that are both uncommon for the region, as well as the state. One outcrop near Logansport is of particular interest by providing an unusual rock habitat for death camus (*Zigadenus elegans*—SR) and tufted hair grass (*Deschampsia cespitosa*—SR), species that elsewhere in Indiana are confined to fens. Other species of note include forked aster (*Eurybia furcata* (Burgess) Nesom—SR), smooth cliff brake fern (*Pellaea glabella*), harebell (*Campanula rotundifolia*), black-fruit mountain ricegrass (*Oryzopsis racemosa*—SR) and a small population of round-leaved serviceberry (*Amelanchier sanguinea*), a species under review for state listing. Other rare species associated with outcrops on or near the river are calamint (*Satureja glabella*—SE) and purple oat grass (*Schizachne purpurascens*—SE). With the exception of one population of the latter in LaGrange County, all known populations of this northern grass are in proximity to the Wabash River. Hanging Rock Natural Area in Wabash County contains examples of interesting limestone outcrop communities bordering the Wabash River.

Sandstone outcrop: Most sandstone outcrops near the Wabash River occur within the Entrenched Valley Section in Warren and Fountain counties. A most spectacular example of this type occurs in Portland Arch Nature Preserve. Here a deep canyon lined with sandstone cliffs provides a refugium for a number of species uncommon to the state and/or natural region. Such examples include white pine (*Pinus strobus*—SR), Canada blueberry (*Vaccinium myrtilloides*—SE), wintergreen (*Gaultheria procumbens*), rock spikemoss (*Selaginella rupestris*—ST), pinnatifid spleenwort (*Asplenium pinnatifidum*), hay-scented fern (*Dennstaedtia punctilobula*), northern bush-honeysuckle (*Diervilla lonicera*—SR), and Forbes' saxifrage (*Saxifraga forbesii* Vasey—SE). Within Indiana, Forbes' saxifrage is confined to sandstone outcrops along the Wabash River and its immediate tributaries. Most of Indiana's populations of the forked aster (*Eurybia furcata* (Burgess) Nesom—SR) are found on sandstone outcrops along and near the Wabash River, although it also occurs on limestone (see above) and mesic gravel slopes. Burgette and Knudson (1976) provide a list of additional species for Portland Arch.

Gravel barrens (Gravel hill prairie): Localized deposits of glacial outwash gravel and sand form a substrate that, where found on steep-sided, south or west-facing slopes, creates a rather xeric environment known as gravel barrens (Homoya 1994) or gravel hill prairies (Post et al. 1985; White & Madany 1978). In Indiana, the most diverse examples of these small communities—each less than 0.5 ha—occur on steep hillsides bordering the Wabash River in the vicinity of Lafayette in Tippecanoe County. The community is conducive to the growth of drought-adapted grasses and forbs, and it harbors species more commonly found in climatically dry communities considerably farther west, e.g., western wallflower (*Erysimum capitatum* (Doug.) Greene—ST), plains muhlenbergia (*Muhlenbergia cuspidata*—SE), and narrow-leaved puccoon (*Lithospermum incisum*—SE). In Indiana these species are mostly confined to the Wabash River corridor. Other rarities of the community include Pitcher's stichwort (*Arenaria patula*—SE), kitten tails (*Besseya bullii*—SE), and disjunct occurrences of post oak (*Quercus stellata*), aromatic aster (*Symphiotrichum oblongifolium* (Nutt.) Nesom—SR) and narrowleaf summer bluets (*Hedyotis ni-*

gricans—SR). Tennessee milkvetch (*Astragalus tennesseensis*—extirpated), a species of the glades and barrens in Tennessee and Alabama with disjunct occurrences in Illinois and Indiana, was collected at only one site in the state, near Lafayette (Stuart 1902). Stuart indicated collecting it from sandy bottomland (along Wea Creek), an unusual habitat for the species. A more expected habitat, and perhaps the seed source for the bottomland plants, would have been the gravel barrens occurring on adjacent slopes. The species has not been collected nor reported in Indiana since 1901. Wea Creek Nature Preserve, located in Tippecanoe County, harbors some of the above listed species.

Fen: Fens—wetland communities formed by upwelling of groundwater flowing in a diffuse manner through a surface layer of peat or muck—occur along most of the course of the Wabash River, but primarily in the portion located in the Central Till Plain. The fens are typically positioned at the bases of slopes and in ravine valleys bordering the river, but can also occur on relatively level terraces between the river and adjacent hills. Community structure can range from forested to graminoid, the latter generally the type with the greatest species diversity. Occurrences of rare or uncommon species include small white lady's-slipper (*Cypripedium candidum*), small yellow lady's-slipper (*C. parviflorum* Salisbury var. *makasin* (Farwell) Sheviak—SR), queen-of-the-prairie (*Filipendula rubra*), and shining ladies'-tresses (*Spiranthes lucida*—SR). Canada burnet (*Sanguisorba canadensis*—SE) is one of the rarest and most localized. Only three extant populations are known, and all occur in fens bordering the Wabash River. The absence of the species in other seemingly prime habitat in the far northern counties is an enigma. Most Indiana occurrences of glade mallow (*Napaea dioica*—SR) are confined to the lowland terraces bordering the upper Wabash River. While there is no apparent natural community where this species occurs today, it might have been a fen (and prairie) edge plant in presettlement times. As almost all of the terrace fens have been converted to agricultural uses, the mallow has persisted only in strips of edge habitat along roadsides and fence rows. Species representative of fens along the Wabash River are listed in Ebinger & Bacone (1981). Small examples of fens bordering the Wabash River occur in Prophetstown State Park in Tippecanoe County.

Tallgrass prairie: Tallgrass prairie vegetation on loam soils occurred on slopes and valleys bordering the Wabash River, especially nearby in those counties that are included within the Grand Prairie Natural Region, *viz.*, Tippecanoe, Warren, and Vermillion. Essentially all of the community has been converted to agriculture or shaded out of existence by trees (due to fire suppression). Remnants are confined to a few pioneer cemeteries and fence rows. In the few remaining square meters of prairie vegetation extant along the Wabash a few rare species persist, including royal catchfly (*Silene regia*—ST), prairie wild hyacinth (*Camassia angusta* (Engel. & Gray)—SE), and prairie violet (*Viola pedatifida* Don.). Additional species for the community in Indiana can be found in Betz (1978). Smith Cemetery Nature Preserve, located in Vermillion County, is one of the few remnants of tallgrass prairie in the region.

Southwestern Lowlands Natural Region.—The Southwestern Lowlands Natural Region is the area of relatively low relief in southwestern Indiana south of the Wisconsinan glacial border and west of the rugged Shawnee Hills. The Wabash River courses through this area from just north of Terre Haute in Vigo County southward to Merom in Sullivan County, at which point the river then begins its course through the floodplain communities found in the Southern Bottomlands Natural Region. The Southwestern Lowlands Natural Region is never far from the Wabash River however, as it borders the Southern Bottomlands from Merom to the river's confluence with the Ohio River in Posey County. The following are rare natural communities and vascular plants of the Wabash River corridor in the Southwestern Lowlands Natural Region.

Sand barrens (sand prairie): Examples of sand barrens occur along the Wabash River from near Lafayette and extending southward; but the most extensive ones, at least historically, were near and south of Terre Haute. Sand barrens are located on eolian sand deposits and are mostly positioned on the leeward side of the river. The sandy substrate is commonly quite dry due to excessive drainage through the coarse-grained material. Historically much of it was dominated by graminoid vegetation interspersed with small growths of oak and hickory trees. Like the fen and loam prairie communities, most sand barrens have been converted to agricultural uses, and thus only very small remnants remain. Rare species associated with sand barrens include heavy sedge (*Carex gravida*—SE), hairy golden-aster (*Heterotheca camporum* (Greene) Shinners var. *camporum*—ST), slender-stalked gaura (*Gaura filipes*—ST), tube penstemon (*Penstemon tubaeflorus*—extirpated), Carolina anemone (*Anemone caroliniana*—extirpated), clustered poppy-mallow (*Callirhoe triangulata*—extirpated), and black hickory (*Carya texana*—SE). The latter three are known in Indiana only from barrens bordering the Wabash River. Additional species of the community can be found in Homoya (1994). Although not in the natural region, a representative example of the type occurs in Tippecanoe County at Granville Sand Barrens Nature Preserve.

Tallgrass prairie: Although deep soil prairie is no longer known to exist along the Wabash River in this natural region, it was documented as occurring there. Place names, such as Prairie Creek and Prairie Creek Township in Vigo County, attest to its former occurrence. Historical accounts by early visitors and pioneers (Thomas 1916), as well as notes taken by the surveyors of the General Land Office (General Land Office 1799–1834), indicate the presence of several prairies in the region. Today along the Wabash River only scattered individual prairie plants have survived, and of the listed rare species, only very old records of royal catchfly (*Silene regia*) are known from the prairie in this area.

Southwestern lowland flatwoods: In the level uplands bordering the Wabash River, especially in the far southern portion of Posey County, are flatwoods that harbor some of the most interesting vegetation in the state. Dominated mostly by post oak (*Quercus stellata*), cherrybark oak (*Q. pagoda*), and shagbark hickory (*Carya ovata*), these flatwoods possess a mix of floodplain forest species and those from prairie and dry forest communities. The wetland species occur in the shallow depressions, e.g., spider lily (*Hymenocallis occidentalis* (Le Conte) Kunth var. *occidentalis*), deciduous holly (*Ilex decidua*), purple fringeless orchid (*Platanthera peramoena* (Gray) Gray), narrow-leaved cattail sedge (*Carex squarrosa*), swamp oval sedge (*C. muskingumensis*), and common wood reed (*Cinna arundinacea*). On the slightly higher and drier areas the prairie and dry forest species can be found, e.g., stiff goldenrod (*Solidago rigida*), blazing star (*Liatris spicata*), rattlesnake master (*Eryngium yuccifolium*), and big bluestem (*Andropogon gerardii*). A more detailed description and species list are found in Aldrich & Homoya (1984). Rare species noted from the community are many, including buffalo clover (*Trifolium reflexum*—SE), eastern eulophus (*Perideridia americana*—SE), broom panic grass (*Dichanthelium scoparium* (Lam.) Gould—SE), clustered fescue (*Festuca paradoxa*—ST), blackfoot quillwort (*Isoetes melanopoda—ST), Wolf bluegrass (Poa wolfii*—SR), rough rattlesnake root (*Prenanthes aspera*—SR), and Wolf spikerush (*Eleocharis wolfii*—SR). Rare species restricted in Indiana to the community type near the Wabash include woodland pinkroot (*Spigelia marilandica*—SE), Buckley's goldenrod (*Solidago buckleyi*—SE), and Lesquereux's mustard (*Lesquerella globosa*—SE). The occurrence of the *Lesquerella* here is remarkable, as it is the only station for the species outside of its known range in the Central Basin of Tennessee and the Inner Bluegrass in Kentucky. Section Six Nature Preserve in Posey County is home to several of the species referenced above.

Southern Bottomlands Natural Region.—The Wabash River flows through the Southern Bottomlands Natural Region from the general area of Merom in Sullivan County to its confluence with the Ohio River in southern Posey County. The lowland region is, as the name implies, "southern," not only because of its location in the state, but also by the geographic affinity of many of its organisms to the southern U.S. The principal communities are wetland and aquatic ones, mainly floodplain forest, swamp, pond, and lake. The following are rare natural communities and vascular plants of the Wabash River corridor in the Southern Bottomlands Natural Region.

Swamp and wet floodplain forest: Of special interest in the natural region are the swamps dominated by bald cypress (*Taxodium distichum*—ST). The most northern natural occurrence for *Taxodium* in the midwestern U.S. is near Vincennes in Knox County (and is within a few kilometers of being the

northernmost in the world). Other rare species include creeping bur-head (*Echinodorus cordifolius*—SE), Amazon sprangletop (*Leptochloa panicoides*—SE), featherfoil (*Hottonia inflata*—ST), cylindric-fruited seedbox (*Ludwigia glandulosa*—ST), bloodleaf (*Iresine rhizomatosa*—SR), Pursh buttercup (*Ranunculus pusillus*—SE), Mississippi buttercup (*Ranunculus laxicaulis* Darby—SE), social sedge (*Carex socialis*—SR), short-bristle horned-rush (*Rhynchospora corniculata*—ST), southern rein orchid (*Platanthera flava* (L.) Lindley var. *flava*—SE), climbing dogbane (*Trachelospermum difforme*—SR), water locust (*Gleditsia aquatica*—SE), water purslane (*Didiplis diandra*—SE), and catbird grape (*Vitis palmata*—SR). Of these, the *Echinodorus*, *Gleditsia*, *Leptochloa*, and *Ludwigia* are confined primarily to the Wabash River corridor. A prime location to see many of these species is in Posey County at Twin Swamps Nature Preserve.

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LITERATURE CITED

Aldrich, J.R. & M.A. Homoya. 1984. Natural barrens and post oak flatwoods in Posey and Spencer counties, Indiana. Proceedings of the Indiana Academy of Science 93:291–301.

Aldrich, J.R., L.A. Casebere & M.A. Homoya. 1986. The discovery of native rare vascular plants in northern Indiana. Proceedings of the Indiana Academy of Science 95:421–428.

Betz, R.F. 1978. The prairies of Indiana. Pp. 25–31, *In* Proceedings of the Fifth Midwest Prairie Conference. (D.C. Glenn-Lewin & R.Q. Landers, eds.). Iowa State University, Ames, Iowa.

Burgette, D.L. & D.M. Knudson. 1976. Plants of Portland Arch Nature Preserve. Station Bulletin No. 141. Department of Forestry and Natural Resources Agricultural Experiment Station. Purdue University. 23 pp.

Ebinger, J.E. & J.A. Bacone. 1981. Vegetation survey of hillside seeps at Turkey Run State Park. Proceedings of the Indiana Academy of Science 90:390–394.

General Land Office Survey Records For Indiana. 1799–1834. Vols. 1–8. Indiana State Archives, Commission On Public Records, Indianapolis.

Gleason, H.A. & A. Cronquist. 1991. Manual of Vascular Plants of Northeastern United States and Adjacent Canada. The New York Botanical Garden. Bronx, New York. 482 pp.

Gray, H.H. 2000. Physiographic Divisions of Indiana. Indiana Geological Report 61. Indiana University. 15 pp.

Homoya, M.A. 1983. Additions to the flora of southern Indiana. Proceedings of the Indiana Academy of Science 92:379–382.

Homoya, M.A. 1988. Additions to the flora of southern Indiana, III. Proceedings of the Indiana Academy of Science 97:449–452.

Homoya, M.A. 1994. Indiana barrens: Classification and description. Castanea 59:204–213.

Homoya, M.A. & D.B. Abrell. 1986. Recent additions to the flora of southern Indiana. Proceedings of the Indiana Academy of Science 95:429–432.

Homoya, M.A., D.B. Abrell, J.R. Aldrich & T.W. Post. 1985. The natural regions of Indiana. Proceedings of the Indiana Academy of Science 94: 245–268.

Homoya, M.A., D.B. Abrell, C.L. Hedge & R.L. Hedge. 1995. Additions to the flora of southern Indiana, V and VI. Proceedings of the Indiana Academy of Science 104:213–221.

Indiana Natural Heritage Program. 2006. Endangered, threatened, and rare vascular plants of Indiana [web application]. Indiana Department of Natural Resources, Indianapolis. Available http: www.in.gov/dnr/naturepr/endanger/etrplants.pdf

Post, T.W., J.A. Bacone & J.R. Aldrich. 1985. Gravel hill prairies of Indiana. Proceedings of the Indiana Academy of Science 94:457–463.

Stuart, W. 1902. Some additions to the flora of Indiana. Proceedings of the Indiana Academy of Science. 1901:282–284.

Thomas, D. 1916. Travels through the western country in the summer of 1816. Pp. 42–135. *In* Indiana As Seen By Early Travelers. (Harlow Lindley, ed.). Indiana Historical Commission, Indianapolis.

White, J. & M.H. Madany. 1978. Classification of natural communities in Illinois. Pp. 309–405. *In* Illinois Natural Areas Inventory Technical Report, Vol. 1. (John White, ed.). Illinois Natural Areas Inventory. Urbana, Illinois.

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2006. Proceedings of the Indiana Academy of Science 115(2):94–102

FOREST COMMUNITIES AND TREE SPECIES OF THE LOWER WABASH RIVER BASIN

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ABSTRACT. The nature of presettlement forests of the Lower Wabash River basin, as documented by the naturalist Robert Ridgway, is presented. Comparisons are made between the composition of the original forest with present-day stands on various floodplain soils. Brief descriptions are given for representative forest stands within the study area, as related to topographic position and/or susceptibility to flooding. Eight natural areas are listed where remnants of original vegetation may be observed. Fifteen tree species that typify southwestern Indiana are described briefly.

Keywords: Floodplain vegetation, forest communities, Lower Wabash Valley, presettlement forests, Robert Ridgway, tree species of Indiana

Some of the most impressive presettlement forest stands of the Eastern Deciduous Forest Biome grew along the southern reaches of the Wabash River, its major tributaries, and associated lowlands (Petty & Jackson 1966). Here during the 1870s and 1880s, naturalist Robert Ridgway (1872, 1882) measured and photographed a number of individual trees that exceeded 150 ft (45 m) in height, and regularly reached diameters 6 feet (1.8 m) or greater on the fertile soils of that region. Forest stands remaining in southwestern Indiana today differ greatly from the vast original wilderness, not only in areal extent, but also in species composition, and in the size of trees present.

Statewide, Indiana forests contain approximately 100 native species that routinely reach tree size at maturity. Of these, 78 species can be found within the Southwestern Lowlands and the Southern Bottomlands Natural Regions of southwestern Indiana (Jackson 2004). A few of these species are unique in their occurrence (in Indiana) to these regions, are of special interest ecologically or taxonomically, or are at or near their northern range limit in that area of Indiana. Nomenclature for tree species follows Gleason & Cronquist (1991).

NATURE OF THE ORIGINAL FOREST AND RECORD TREES

From early reliable accounts (Ridgway 1882; DenUyl 1958; Lindsey et al. 1961) of the nature and grandeur of the forests of the Lower Wabash River Valley, it is doubtful that more magnificent stands of hardwood trees occurred anywhere in the Eastern Deciduous Forest Biome. The height, girth, and density of trees growing there were seldom exceeded even in the moist cove forests of the southern Appalachian Mountains (Jackson unpubl. data). Considering that the Wabash River drains some of the finest glaciated landscape of midwestern U.S., it is understandable that the deep, fertile, well-drained soils, with constant moisture available, would produce an original forest which now seems improbable to many people.

The early naturalist Robert Ridgway, who grew up in the Lower Wabash Valley, and who spent extended periods there during the 1870s and 1880s photographing (e.g., Figs. 1, 2) and measuring trees, described the area and its forest: "... from a little below Vincennes (Indiana) to near New Harmony (Illinois), an exceedingly heavy virgin forest, some of the heaviest hardwood forest I have seen—as I have twice visited the Tropics (Central America)—covered almost the entire flood plain of the Wabash on the Indiana side. If the forest is viewed from a high bluff, it presents the appearance of a compact, level sea of green, apparently almost endless, but bounded by the line of wooded bluffs three to seven miles back from the river. . . . My estimate was that the tree top line of the virgin forest along the Lower Wabash . . . may have been as much as 120 feet. It was remarkably uniform, forming

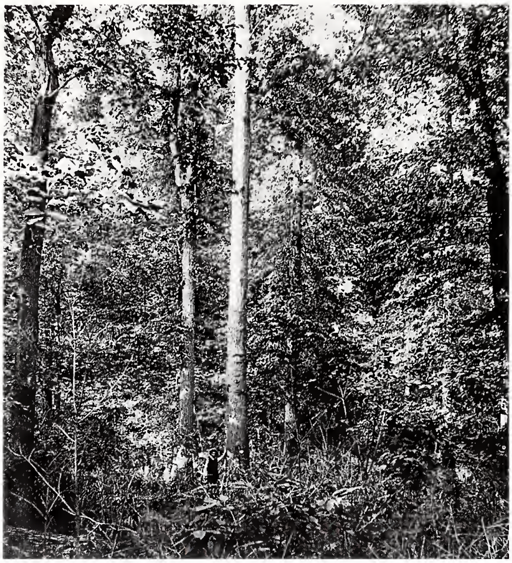

Figure 1.—View (July 1890) of pin oak (*Quercus palustris* Muenchh.) in the Wabash Bottoms, 4 or 5 miles (7–9 km) south of Vincennes, Indiana. (Robert Ridgway photo)

a practically straight level line, with only here and there the dome-shaped top of some species which grew larger than most others (usually a sycamore, pecan, or tulip tree), lifted above the general level." (Ridgway 1872)

Ridgway's actual measurements of height of trees still living, and those he observed as recently cut, substantiated his earlier estimates. His careful measurements of the heights by triangulation and lengths of actual felled trees allowed him to determine the average tree-top level at 130 feet (40 m), and that "by no means infrequent monarchs attained a height of more than 180 feet (55 m), and that the tallest sycamores and tulip trees approached 200 feet (60 m) in height." (Ridgway 1872)

Ridgway's diameter measurements were equally impressive. Bald cypress (*Taxodium distichum* (L.) Rich.) stems that were recently cut were 9–10 feet (2.7–3 m) across, whereas some harvested earlier exceeded the dimensions of any stumps, or those still standing (Ridgway 1876). Other trees measured by Ridgway included a sycamore (*Platanus occidentalis* L.) in Gibson County located nearly opposite Mt. Carmel, Illinois, at 15 feet (4.6 m) diameter at 10 feet (3 m) above ground, whose height as measured by dendrometer was "probably the tallest tree east of California," in Ridgway's (1882) words. He also stated that, "In the same half mile square, I measured, on this same day, twelve sycamores which averaged near 8 feet (average girth of 23½ feet) in diameter and 127 feet spread of top." Additionally, four tulip trees (*Liriodendron tulipifera* L.) within a single photograph taken in 1888 by Ridgway ranged from 5–7 feet (1.5–2.1 m) dbh each. (The term dbh, stands for diameter at breast height, the forester's term for the standard height measurement for trees, i.e., at 54 inches or 1.37 m above ground.) A Shumard's red oak (*Quercus shumardii* Buckley) below the White River mouth was 6 feet (1.8 m) in diameter at 12 feet (3.7 m) high (Figure 2). Within 100 yards (90 m) of the above oak were two black walnuts (*Juglans nigra* L.), each 6 feet (1.8 m) in diameter above the butt swell.

Lindsey et al. (1961) recorded an 81.5 inches (2.1 m) in diameter standing bald cypress in Little Cypress Swamp in Knox County that they speculated to be the largest living tree in Indiana at that time. Other large individual trees (> 48 inches or 1.2 m dbh) that they recorded along the Wabash River in Indiana during their field study which lasted from 1955–1959 were: silver maple (*Acer saccharinum* L.) 72.2, 70.5 and 63.0 inches (1.8, 1.8 and 1.6 m); hackberry (*Celtis occidentalis* L.) 69.1 inches (1.8 m); cottonwood (*Populus deltoides* Marshall) 67.1 inches (1.7 m); black willow (*Salix nigra* Marshall) 67.3 and 64.3 inches (1.7 and 1.6 m); northern red oak (*Quercus rubra* L.) 56.0 inches (1.4 m); and pin and bur oak (*Quercus palustris* Muenchh. and (*Q. macrocarpa* Michx.) 50.0 inches (1.3 m). In their 1961 study, Lindsey et al. did not record tulip tree as present on floodplain sites in recent times, but apparently the species was common there on well-drained soils, and reached record sizes in Ridgway's day (DenUyl 1958). Almost all well-drained sites have now been cleared and are in agricultural production.

In the low-ground section of Hemmer Woods in Gibson County, tulip tree still occurs in record sizes. In an 11.3 acre (4.6 ha) full census, Jackson (1969a, b) recorded three tulip trees that exceeded 50 inches (1.3 m) dbh, 10 over 40 inches (1.0 m), and 20 greater than 30 inches (0.8 m). Twelve species in the stand had a total of 61 stems > 30 inches dbh,

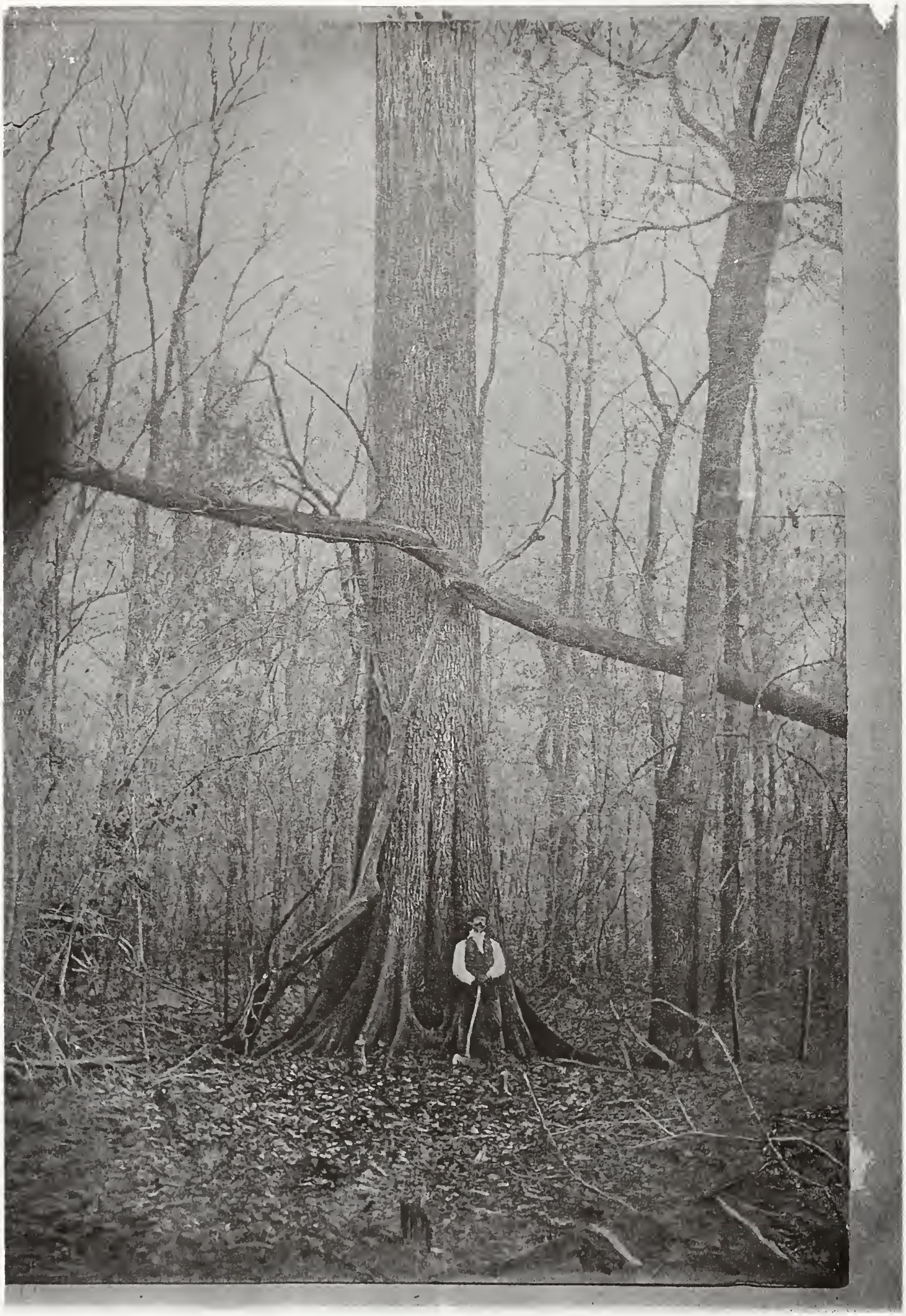

Figure 2.—Shumard's Red Oak (*Quercus shumardii* Buckley) in the original forest of the Wabash Bottoms. Tree is 6 feet (1.8 m) dbh, 12 feet (3.6 m) at base. (Robert Ridgway photo, date unknown)

or 5.4/acre. The largest tulip tree at 54.6 inches or 1.4 m dbh in 1969, may be the largest forest-grown tulip tree in the State of Indiana. At 151 feet (46 m) tall and 53 feet (16 m) clear length, it rivals the height of those forest giants of Ridgway's day. Overall, Hemmer Woods is remarkable in having 32 species above 10 cm in diameter, with an interesting mix of both hydric and mesic species represented. Tulip tree and sweet gum (*Liquidam-*

bar styraciflua L.) dominate the stand at a combined importance value of 25%.

FOREST CHANGES FROM PRESETTLEMENT TIME TO PRESENT

Not only has the essentially unbroken presettlement forest been reduced by clearing to a remnant of its former grandeur, major changes have also occurred in the species present, and in forest composition generally.

The Wabash River is most unusual in that its overall flow patterns remain essentially unmodified by major structural changes such as construction of large reservoirs, channelization, dredging, and the like. As such, it is one of the largest and longest essentially free-flowing rivers of North America south of Canada. However, forest clearing, artificial drainage of agricultural land, destruction of wetlands, and extensive paved surfaces within the watershed, have greatly increased runoff rates and all have contributed to increased frequency, height, and duration of floods during the past two centuries. Such changes in the flooding regime are likely the primary cause of the definite shifts in the species composition of forests of the Lower Wabash Valley since presettlement time.

Two important ecological studies examined the composition of presettlement forests within the region. Dr. William Crankshaw, a long-term professor of ecology at Ball State University, examined the nature of edaphic controls of tree distribution in the presettlement forests south of the Late Wisconsinan glacial boundary, as his Ph.D. research at Purdue University (Crankshaw 1964; Crankshaw et al. 1965). His study included data on more than 60,000 trees that the General Land Office (GLO) surveyors selected as bearing or witness trees to mark section corners during the original survey of land now comprising southern Indiana.

Crankshaw constructed stand tables of tree species present on all major soil types represented on floodplain, terrace, and upland landforms within the region. He found American beech (*Fagus grandifolia* Ehrh.) to be present on six widespread floodplain soil series (Eel, Gesesee, Morganfield, Pope, Ross, and Shoals), ranging from 7–33% of stand importance on different soils; sugar maple to be present on four soil series (Eel, Genesee, Pope, and Ross), at 7–20% importance; and tulip tree on three (Eel, Morganfield, and Pope), at 5–7% importance. White oak (*Quercus alba* L.) was also present at 13% on the Eel soil series. Combined, beech, sugar maple, and tulip tree represented 46% of the stand importance on Eel silt loam soils; while beech and sugar maple totaled 48% on Genesee loam soils. None of these mesic to dry-mesic tree species is found on floodplain soils within the Wabash River valley today (Lindsey et al. 1961). Changes in the flooding regime during the past 200 years are believed to be the primary cause of their exclusion from these sites today.

Ellen Donselman's (1975) Master's thesis at Indiana State University contained a comparison of forest composition of Vigo County, as based on the 1814 GLO land survey, with data obtained from sampling 14 of the best remaining contemporary stands within the county during the 1974 field season. Her analysis centered on comparing the two samplings separated by 160 years, by dividing the county physiographically into floodplain, terrace, upland slope, and upland flat units. Each unit for each time period was considered as a separate forest stand.

The floodplain comparison for the two time periods is especially revealing. In 1814, of a 345-tree sample, beech, sugar maple, and tulip tree collectively comprised 14% of stand importance, with white oak and black oak combined representing another 20%. Silver maple was present in 1814 at only 4%; cottonwood was not listed by the GLO surveyors. In the 1974 sampling of remaining floodplain stands, beech, sugar maple, tulip tree, and the two oak species were absent, whereas silver maple and cottonwood combined totaled 60% of stand importance. Again, differences in forest composition during the intervening 160 years are believed to have resulted primarily from changes in the flooding regime.

That tulip trees still occur in all size classes in the bottomland stand at Hemmer Woods (Jackson 1969b) represents a somewhat different situation. First, the creek that runs through Hemmer Woods is small, strongly meandering, and carries a relatively small water volume following most rains. Any overflow that occurs is likely shallow and of short duration. Further, a drainage ditch cut across adjacent farmland in years past has lowered the water table several feet below the general land surface. Also, the larger tulip trees likely began growth in the presettlement forest (or during the early years of Indiana's history), and continue to survive. Additionally, the presence of tulip trees in all size classes from 4 inches (10 cm) upward to > 50+ inches (1.3 m) dbh (Jackson 1969b), suggests that tulip tree regeneration has been occurring without interruption in Hemmer Woods since presettlement time.

Changes in the terrace communities of Vigo County were almost equally revealing. The major terrace system in Vigo County (where much of the City of Terre Haute is located) is mainly underlain by sands and gravels that were deposited during the Pleistocene by the Maumee Torrent, a deluge that drained much of glacial Lake Maumee when a moraine near Fort Wayne was breached by flood waters. Since these terrace soils are relatively dry, they supported prairie vegetation, for the most part. However, in the forest stands that did occur on the terrace in 1814, beech and sugar maple represented 13% of a 227-tree sampling by the surveyors, and tulip tree was not recorded. Oak and hickory species combined totaled 58% of stand importance. Donselman's 1974 sample revealed that beech and sugar maple each represented < 1% of the stands, tulip tree 8%, whereas oak and hickory combined were similar in importance to 1814 at 52% (Donselman 1975).

PRESENT FOREST COMMUNITIES TYPICAL OF SOUTHWESTERN INDIANA NATURAL REGIONS

Forested areas found today in the two natural regions of southwestern Indiana are largely present on flood-prone lands, river margins, sites with high water tables at or near the surface (at least seasonally), or on other tracts unsuited for agriculture or development. Although both glaciated and unglaciated landscapes are represented in far southwestern Indiana, glaciation there occurred long ago, and apparently has little effect on present forest composition (Lindsey et al. 1961). Instead, the impact of southerly weather systems originating over the Gulf of Mexico, and their attendant extension up the Mississippi, Ohio, and Wabash river valleys, is far more influential in extending the northward range of a number of tree species with southern affinities (Lindsey et al. 1961; Abrell 1997), some of which are described below.

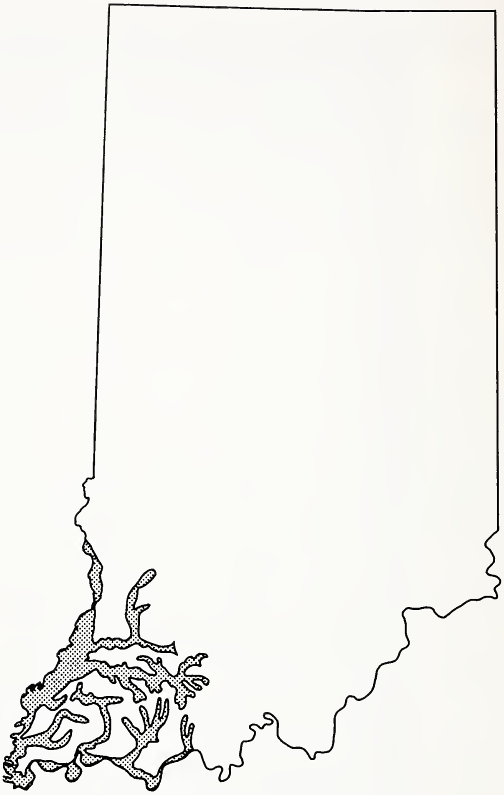

Figure 3.—The Southern Bottomlands Natural Region of Indiana. (Graphic from *The Natural Heritage of Indiana* 1997)

The nature of forest stands is strongly influenced also, by subtle changes in elevation, hence by the frequency, height, and duration of flooding, and by notable differences in moisture conditions of the soils (Lindsey et al. 1961). The deeper sloughs and swamps of the Southern Bottomlands Natural Region (Fig. 3) of far southwestern Indiana that hold standing water throughout the year, or nearly so, range from essentially pure stands of bald cypress, to stands mixed with silver maple, river birch (*Betula nigra* L.), pecan (*Carya illinoensis* (Wangenh.) K. Koch), swamp cottonwood (*Populus heterophylla* L.), sugarberry (*Celtis laevigata* Willd.), and locally, water locust (*Gleditsia aquatica* Marshall), or pumpkin ash (*Fraxinus profunda* (Bush) Bush). Joining this forest mosaic at sites with prolonged, but not continuous, standing water, are communities of such characteristic species as silver maple, cottonwood, sycamore, green ash (*Fraxinus pennsylvanica* Marshall), overcup oak (*Quercus lyrata* Walter), pecan, shellbark hickory (*Carya laciniosa* (Michx. f.) Loudon), sugarberry, and black willow. Slightly better-drained sites may be dominated by swamp white (*Quercus bicolor* Willd.), swamp chestnut (*Q. michauxii* Nutt.), Shumard's red, and bur oaks, along with shellbark hickory, hackberry, American elm (*Ulmus americana* L.), or, locally, green hawthorn (*Crataegus viridis* L.), or Kentucky coffee tree (*Gymnocladus dioica* (L.) K. Koch). Flatwoods, at slightly higher elevations, but still poorly drained—often internally—may have prolonged periods of standing water, and contain post (*Quercus stellata* Wangenh.), cherrybark (*Q. pagoda* Raf.), and pin oaks, plus sometimes sweet gum (*Liquidambar styraciflua* L.), green ash, and American elm (Abrell 1997).

A distinctive non-arborescent plant species strongly characteristic of this natural region is giant cane (*Arundinaria gigantea* (Walter) Chapman), a bamboo that grows on very fertile soils. These "cane breaks," which were once very extensive, are now almost entirely converted to agriculture. Also present are such shrubs as swamp privet (*Forestiera acuminata* (Michx.) Poiret), catbird grape (*Vitis palmata* M. Vahl.), and woolly pipe vine (*Aristolochia tomentosa* Sims); and such showy herbs as spider lily (*Hymenocallis caroliniana* (L.) Herbert) and featherfoil (*Hottonia inflata* Elliott). Characteristic vertebrates include the swamp rabbit (*Sylvilagus aquaticus* (Bachman), (very rare in Indiana), plus such reptilian species that are rare in Indiana as the eastern mud turtle (*Kinosternon subrubrum subrubrum* (Lacepede)), and the cottonmouth moccasin (*Agkistrodon piscivorus leucostoma* (Troost)) (Abrell 1997).

The Southwestern Lowlands Natural Region parallels the Wabash River from the Ohio River north to the Wisconsinan glacial boundary in Vigo and Clay counties (Fig. 4). Standing at higher elevations, and generally much better drained than the preceding natural region, the plant communities are quite different. The southern section, which was shaped and leveled early on by Illinoian glaciation, is characterized by black ash (*Fraxinus nigra* Marshall) swamps in the lowest-lying areas, alternating with poorly-drained flatwoods which contain pin and shingle (*Quercus imbricaria* Michx.) oak, and shagbark hickory (*Carya ovata* (Miller) K. Koch), red (*Acer rubrum* L.) and silver maple, hackberry, and green ash (Hedge 1997).

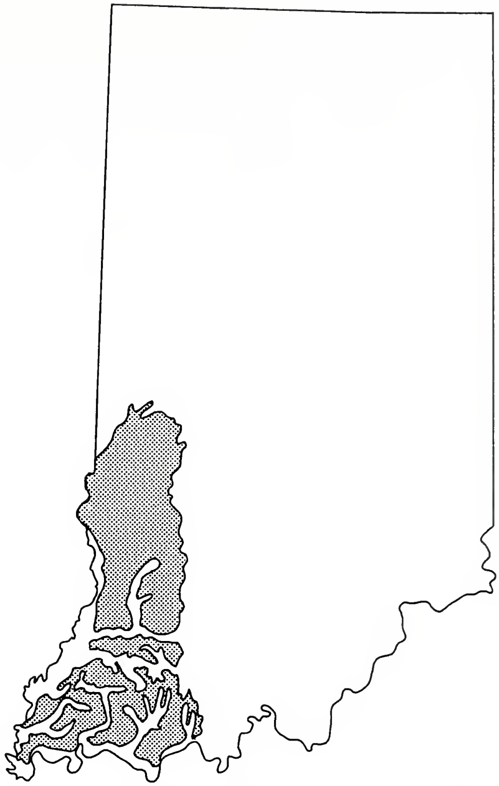

Figure 4.—The Southwestern Lowlands Natural Region of Indiana. (Graphic from *The Natural Heritage of Indiana* 1997).

The southernmost section beyond the reach of glaciation has a mix of forested and non-forested communities, ranging from marsh to seep spring to sandstone cliffs, as topography changes markedly throughout the section. The flatwoods here are different in that a mix of prairie grasses and forbs intermingles with southern bottomland trees such as cherrybark, Shumard's red, swamp white, and pin oaks, along with shellbark hickory, sweet and black (*Nyssa sylvatica* Marshall) gum, and green ash (Hedge 1997).

Largely from Vincennes northward to Terre Haute is a narrow band of scattered sand ridges and dunes formed by aeolian sands that were blown eastward by westerly winds from the poorly-vegetated Wabash River floodplain at the close of the Pleistocene (Petty & Jackson 1966). This section had primarily prairie and barrens vegetation along with a scatter of black (*Quercus velutina* Lam.) and blackjack (*Q. marilandica* Muenchh.) oaks. A small remnant of sand prairie is protected at Little Bluestem Prairie Nature Preserve in Vigo County north of Terre Haute (Strait & Jackson 1986). On sites less steep, and with improved soil moisture, oak-hickory forest, dominated by white, red (*Q. rubra* L.), and black oak, along with shagbark and pignut (*Carya glabra* (Miller) Sweet) hickory, was more prevalent (Hedge 1997).

NATURAL AREAS OF THE LOWER WABASH VALLEY THAT CONTAIN REMNANTS OF ORIGINAL VEGETATION

Relatively few high quality remnants of original vegetation have escaped the pervasive clearing and development that has systematically altered the majority of the Indiana landscape during the past two centuries. The highly fertile soils of the Wabash Valley, and the transportation advantages of the river itself, have resulted in greater changes in this region, than those that occurred in some other parts of the State.

Seven natural areas in Indiana, plus one in Illinois are listed below. (Information excerpted largely from INDR Nature Preserves Directory 1995).

1. Ashumbala Nature Preserve (Vanderburgh and Warrick counties): 63 acres (25.5 ha). Contains one of the longest and least-modified stretches of Ohio River Floodplain Forest in Indiana. The trees are mostly silver maple, cottonwood, and black willow, plus green hawthorn and swamp cottonwood also present.
2. Flesher Woods Nature Preserve (Vigo County): 36 acres (14.6 ha). High quality floodplain forest of predominately silver maple, green ash, shellbark hickory, pecan, and bur oak. Probably the least-disturbed floodplain forest in Vigo County.
3. Goose Pond Cypress Slough Nature Preserve (Posey County): 60 acres (24.3 ha). A portion of a three-mile (4.8 km) long cypress slough that contains mostly a bald cypress-green ash-silver maple forest community.
4. Hemmer Woods Nature Preserve (Gibson County): 73 acres (29.6 ha). A Registered National Natural Landmark. Contains both upland oak-hickory forest, plus a very high quality bottomland stand dominated by tulip tree, sweet gum, sycamore, red maple, and elm (Jackson 1969a, b).
5. Little Bluestem Prairie Nature Preserve (Vigo County): 8+ acres (3.3 ha). Likely the only sand prairie remaining in Indiana. Dominated by little bluestem grass (*Schizachyrium scoparium* (Michx.) Nash)), and other herbs, along with a scatter of black oak (Strait & Jackson).
6. Twin Swamps Nature Preserve (Posey County): At 598 acres (242 ha), it is one of Indiana's largest nature preserves, and contains a swamp cottonwood-bald cypress-overcup oak community. The preserve has a boardwalk for visitor enjoyment of the high-quality swamp forest, the herb featherfoil, plus such sought-after birds as prothonotary warblers.
7. Wesselman Woods Nature Preserve (Vanderburgh County): 197 acres (79.8 ha). A Registered National Natural Landmark. This nearly-flat forest of exceptional quality is dominated by sweet gum and tulip tree, along with Shumard's red and pin oak, green ash, and red maple (Lindsey et al. 1969). The preserve has a fine nature center.
8. Beall Woods State Park (Wabash County, Illinois): 280 acres (113.4 ha). This excellent remnant of original forest has both upland and bottomland segregates. The lowland stand, which occurs on both sides of Sugar Creek where it joins the Wabash River, has 31 tree species present, led by Shumard's red and bur oak, sweet gum, American elm, shellbark hickory, and silver maple. Lindsey (1962) listed this stand as having the highest basal area of any midwestern forest then known.

SOUTHWESTERN TREE SPECIES OF SPECIAL INTEREST

(abridged from Jackson 2004)

Bald cypress (*Taxodium distichum* (L.) Rich): Characteristic of deep swamps, sloughs, oxbows, and slough-like creeks, usually with standing water much of the year. Occurred naturally in only five counties of far southwestern Indiana. Now widely planted.

Sweet gum (*Liquidambar styraciflua* L.): Widespread in wet bottomland forests and flatwoods throughout the Lower Wabash River basin from Parke and Vigo counties southward to the Ohio River. Widely planted as an ornamental.

Sugarberry (*Celtis laevigata* Willd.): Often found in swampy woods of low-lying sites, streamsides, and flooded bottomlands from Sullivan Couny south to the Ohio River. Occasional on moist slopes or uplands.

Pecan (*Carya illinoensis* (Wangenh.) K. Koch): Occurs on fertile, moist soils of bottomlands along the Wabash, White, and Ohio rivers, and their tributary streams, from Fountain and Vermillion counties southward in Indiana and adjacent Illinois.

Swamp cottonwood (*Populus heterophylla* L.): Found in deep swamps, low wet woods, and on waterlogged soils in southwestern Indiana from Vigo and Clay counties southward to the Ohio River. Also widely scattered in northern Indiana.

Overcup Oak (*Quercus lyrata* Walter): Occurs on very wet sites on floodplains, and in forested swamps, and sloughs of southwestern Indiana from Sullivan County southward. Very tolerant of extended flooding.

Swamp chestnut oak (*Q. michauxii* Nutt.): Found in low wet woods, and some streambottom forests of far southwestern Indiana, from Knox and Daviess counties south to the Ohio River. Formerly called cow oak by the pioneers.

Cherrybark oak: (*Q. pagoda* Raf.): Mainly in bottomland forests or swamps, and on flats along streams (occasionally on dry sites) of a seven-county area of far southwestern Indiana. Sold as red oak for timber.

Post oak (*Q. stellata* Wangenh.): Usually found on poor soils—from wet, springponded flatwoods to dry woods on steep slopes. Species is ecologically bi-modal, with wet and dry mesic segregates represented. Occurs from Greene County south.

Southern red oak (*Q. falcata* Michx.): Typically on dry, poor upland ridges, but sometimes also in flatwoods and bottomland forests from Knox and Daviess counties southward, in our area of interest. Sold as red oak as timber.

Water locust (*Gleditsia aquatica* Marshall): Known only from Knox, Gibson, and Posey counties in Indiana, and in adjacent Illinois. Occurs only in low swampy woods with roots frequently submerged for several months each year.

Green hawthorn (*Crataegus viridis* L.): Usually occurs in low wet woods, or along stream banks. Known from only five counties in far southwestern Indiana.

Winged elm (*Ulmus alata* Michx.): Occurs typically on dry ridges, bluffs, and in old fields, but occasionally in low woods. Confined to a several county area from Knox and Daviess counties southward in our region of Indiana.

Persimmon (*Diospyros virginiana* L.). Generally widespread in the southern half of Indiana from Vermillion and Parke counties south continuously to the Ohio River. Usually in clearings, old fields, and fence rows; occasionally in more mature forests. Very widely planted.

Pale hickory (*Carya pallida* (Ashe) Engler & Graebner): Rarely encountered and endangered in Indiana and apparently confined (usually) to fine sandy soils of Knox, Daviess, and Posey counties.

LITERATURE CITED

Abrell, D.B. 1997. A taste of the South: the southern bottomlands natural region. Chapter 22, Pp. 177–183, *In* The Natural Heritage of Indiana. (M.T. Jackson, ed.). Indiana University Press, Bloomington. 482 pp.

Crankshaw, W.B. 1964. The Edaphology of Tree Species in Presettlement Indiana South of the Late Wisconsin Glacial Border. Ph.D. dissertation, Purdue University, West Lafayette, Indiana. 115 pp.

Crankshaw, W.B., S.A. Qadir &d A.A. Lindsey. 1965. Edaphic Controls of the Tree Species in Presettlement Indiana. Ecology 46:688–698.

DenUyl, D. 1958. Forests of the lower Wabash bottomlands during the period 1870–1890. Proceedings of the Indiana Academy of Science 68: 244–248.

Donselman, E.O. 1975. A Chronological Comparison of the Vegetation of Vigo County, Indiana: Presettlement (1814) *versus* Contemporary (1974). M.A. thesis, Indiana State University, Terre Haute, Indiana. 131 pp.

Gleason, H.A. & A. Cronquist. 1991. Manual of Vascular Plants of Northeastern United States and Adjacent Canada. The New York Botanical Garden, Bronx, New York. 910 pp.

Hedge, R.L. 1997. Sandhills and old till: the southwestern lowlands natural region. Chapter 21, Pp. 184-187, *In* The Natural Heritage of Indiana.

(M.T. Jackson, ed.). Indiana University Press, Bloomington.482 pp.

INDR. 1995. Indiana's Dedicated Nature Preserves Directory. Division of Nature Preserves, IDNR, Indianapolis, Indiana. Unpaged.

Jackson, M.T. 1969a. Hemmer Woods: an outstanding old-growth lowland forest remnant in Gibson County, Indiana. Proceedings of the Indiana Academy of Science 78:245–254.

Jackson, M.T. 1969b. Hemmer Woods. Chapter 18, Pp. 98–101, *In* Natural Areas in Indiana and Their Preservation. (Lindsey, A.A., D.V. Schmelz & S.A. Nichols, eds.) University of Notre Dame Press, Notre Dame, Indiana. 594 pp.

Jackson, M.T. (ed.). 1997. The Natural Heritage of Indiana. Indiana University Press, Bloomington. 482 pp.

Jackson, M.T. 2004. 101 Trees of Indiana. Indiana University Press, Bloomington. 364 pp.

Jackson, M.T. (unpublished). Field Data on the Forest Composition of Old-growth Forests in Great Smoky Mountains National Park. Unpubl. Data from field trips (1965–2000).

Lindsey, A.A. 1962. Analysis of an original forest of the lower Wabash floodplain and upland. Proceedings of the Indiana Academy of Science 72: 282–287.

Lindsey, A.A., R.O. Petty, D.K. Sterling & W. VanAsdall. 1961. Vegetation and environment along the Wabash and Tippecanoe rivers. Ecological Monographs 31:105–156.

Lindsey, A.A., D.V. Schmelz & S.A. Nichols. 1969. Natural Areas in Indiana and Their Preservation. University of Notre Dame Press, Notre Dame, Indiana. 594 pp.

Petty, R.O. & M.T. Jackson. 1966. Plant Communities. Chapter 16, Pp. 264–296, *In* Natural Features of Indiana. (A.A. Lindsey, ed.). Indiana Academy of Science, Indianapolis. 600 pp.

Ridgway, R. 1872. Notes on the vegetation of the lower Wabash Valley. American Naturalist 6: 658–665.

Ridgway, R. 1876. The Little Cypress Swamp of Indiana. Field and Forest 2:93–96.

Ridgway, R. 1882. Notes on the native trees of the lower Wabash and White River valleys in Illinois and Indiana. U.S. National Museum Proceedings 1882:49–88.

Strait, R.A. & M.T. Jackson. 1986. An ecological analysis of the plant communities of Little Bluestem Prairie Nature Preserve: pre-burning *versus* post-burning. Proceedings of the Indiana Academy of Science 95:447–452.

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CURRENT STATUS OF FRESHWATER MUSSELS (ORDER UNIONOIDA) IN THE WABASH RIVER DRAINAGE OF INDIANA

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ABSTRACT. Seventy-five species of freshwater mussels (Order Unionoida) have historically inhabited the Wabash River drainage of Indiana. Nine of these species have always been restricted to Wabash River tributaries and never maintained reproducing populations in the mainstem Wabash River. Of the 66 remaining species, 18 are currently considered extirpated from the entire drainage and 18 maintain reproducing populations only in Wabash River tributaries. Currently, 30 species maintain reproducing populations in the mainstem Wabash River, which represents a 55% reduction in its freshwater mussel fauna. To date, the entire Wabash River drainage of Indiana has seen a 24% reduction in its freshwater mussel fauna.

Keywords: Freshwater mussels, Wabash River

The freshwater mussel (Order Unionoida) fauna of the Wabash River drainage has been well documented historically. Stein (1881) attempted the first complete list of the 'molluscous fauna of Indiana,' and referenced many species as inhabiting the Wabash River and its tributaries. Call (1894, 1896, 1897, 1900), Blatchley & Daniels (1903), Daniels (1903, 1915), and Goodrich & van der Schalie (1944) continued to add to the knowledge of Indiana's mollusca fauna and provided invaluable information on those species found in the Wabash River drainage.

Three important Wabash River studies were completed during the 1960s and 1970s. Meyer (1968) and Krumholz et al. (1970) studied the commercially valuable species of the Wabash and White rivers. Clark (1976) inventoried mussels from the lower Wabash River.

Between 1987 and 1991, Cummings et al. (1992) sampled 100 sites in the Wabash River drainage, including 53 sites on the mainstem Wabash River. Several of the lower Wabash River sites sampled by Cummings et al. (1992) were re-sampled in 1996 by Frankland (1996). Ball & Schoenung (1996) and EnviroScience (2006) intensively sampled freshwater mussels at several locations in the upper mainstem Wabash River. Page et al. (1992) and Cummings & Mayer (1997) provide information on the status of freshwater mussels in the Wabash River drainage of Illinois.

Many of the larger tributaries of the Wabash River have also had recent survey work completed (from upstream to downstream): Salamonie River (Ecological Specialists, Inc. 1995), Mississinewa River (Ecological Specialists, Inc. 1995), Eel River (upper Wabash River) (Henschen 1987), Tippecanoe River (Cummings & Berlocher 1990; Cummings et al. 1992; Ecological Specialists, Inc. 1993, 1998; Ball & Schoenung 1996; Commonwealth Biomonitoring 2005; EnviroScience 2006), Middle Fork Wildcat (Henschen 1990), small streams of Tippecanoe County (Myers-Kinzie et al. 2001), Jordan Creek (Szafoni et al. 2000), Sugar Creek (middle Wabash River tributary) (Lewis 1991), Brouilletts Creek (Tiemann 2005), East Fork White River drainage (Cummings et al. 1992; Ball & Schoenung 1996; Harmon 1998; Clarke et al. 1999; EnviroScience 2006), West Fork White River drainage (Cummings et al. 1992; Henschen 1993, 1995; L. Bowley, Muncie Bureau of Water Quality pers. comm.), and Patoka River (Ecological Specialists, Inc. 2001). Figure 1 illustrates the recent collections cited here, which include samples from 1987–2004.

In addition to this information, the Wildlife Diversity Section, Division of Fish and Wildlife, Indiana Department of Natural Resources, collected freshwater mussel information

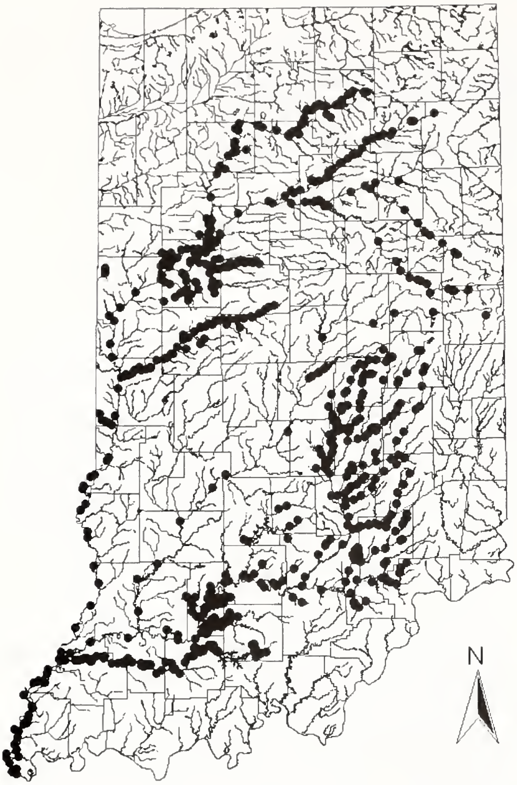

Figure 1.—Freshwater mussel sample locations reported from cited literature for the Wabash River drainage, Indiana (1987–2004).

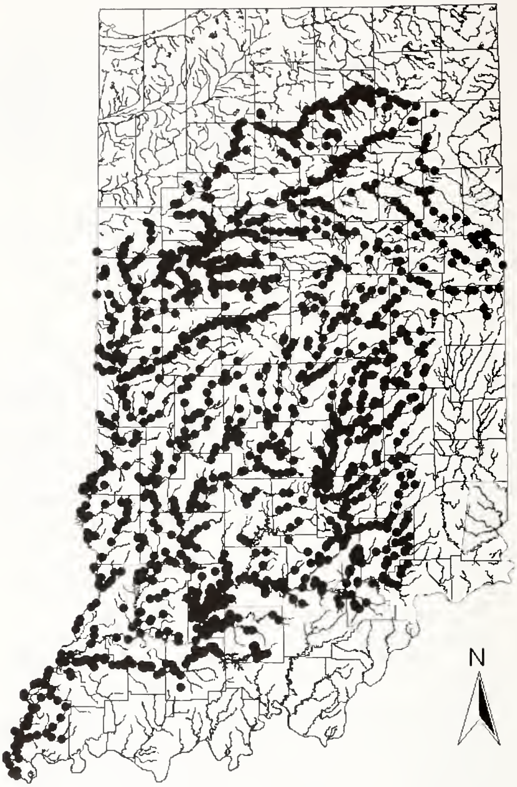

Figure 2.—Freshwater mussel sample locations reported from cited literature and collected by the Wildlife Diversity Section, Indiana Department of Natural Resources, for the Wabash River drainage, Indiana (1987–2006).

from nearly 900 sites within the Wabash River drainage between 1995–2006 (Fig. 2). This information, along with the previously cited surveys, was used to determine the current status of freshwater mussel species within the Wabash River drainage of Indiana.

METHODS

Several different collecting methods were used in the previously cited surveys; the individual reports should be reviewed to determine the specific methods used by those researchers.

An informal sampling design (Strayer & Smith 2003) was utilized for most of our surveys within the Wabash River drainage. Sampling locations were chosen to provide information from watersheds where few or no previous freshwater mussel surveys had been completed. Locations were waded and visually (if possible) and physically searched for live freshwater mussels and dead shell material. At locations where visibility was limited, the stream bottom was searched with hands or shoed-feet.

Live freshwater mussels were identified onsite and returned; representative dead shell material was retained from most locations. Species lists indicating the best condition of shell material (live, fresh dead, weathered dead, or subfossil) encountered were prepared for all sampled locations. All shell material retained from our sampling efforts is currently vouchered at the Atterbury Fish and Wildlife Area, Edinburgh, Indiana.

Besides the specific freshwater mussel sampling described, additional information was obtained incidentally while completing survey work for fishes. Notes were made on live freshwater mussels and shell material encountered, although no formal surveys were completed.

Table 1.—Current status of freshwater mussels (Order Unionoida) in the Wabash River drainage of Indiana. Scientific and common names follow Turgeon et al. (1998). L = reproducing populations of species still found in mainstem Wabash River and its tributaries; XT = reproducing populations of species historically found in mainstem Wabash River but now restricted to its tributaries; T = reproducing populations of species always restricted to Wabash River tributaries; X = species extirpated from entire Wabash River drainage.

Species	Status
Family Margaritiferidae	
Cumberlandia monodonta (spectaclecase)	X
Family Unionidae	
Actinonaias ligamentina (mucket)	L
Alasmidonta marginata (elktoe)	L
Alasmidonta viridis (slippershell mussel)	T
Amblema plicata (threeridge)	L
Anodonta suborbiculata (flat floater)	T
Andontoides ferussacianus (cylindrical papershell)	T
Arcidens confragosus (rock pocketbook)	XT
Cyclonaias tuberculata (purple wartyback)	L
Cyprogenia stegaria (fanshell)	XT
Ellipsaria lineolata (butterfly)	XT
Elliptio crassidens (elephantear)	XT
Elliptio dilatata (spike)	XT
Epioblasma flexuosa (leafshell)	X
Epioblasma obliquata perobliqua (white catspaw)	X
Epioblasma personata (round combshell)	X
Epioblasma propinqua (Tennessee riffleshell)	X
Epioblasma sampsonii (Wabash riffleshell)	X
Epioblasma torulosa rangiana (northern riffleshell)	X
Epioblasma torulosa torulosa (tubercled blossom)	X
Epioblasma triquetra (snuffbox)	XT
Fusconaia ebena (ebonyshell)	XT
Fusconaia flava (Wabash pigtoe)	L
Fusconaia subrotunda (longsolid)	X
Hemistena lata (cracking pearlymussel)	X
Lampsilis abrupta (pink mucket)	X
Lampsilis cardium (plain pocketbook)	L
Lampsilis fasciola (wavyrayed lampmussel)	L
Lampsilis ovata (pocketbook)	L
Lampsilis siliquoidea (fatmucket)	L
Lampsilis teres (yellow sandshell)	L
Lasmigona complanata (white heelsplitter)	L
Lasmigona compressa (creek heelsplitter)	T
Lasmigona costata (flutedshell)	L
Leptodea fragilis (fragile papershell)	L
Leptodea leptodon (scaleshell)	X
Ligumia recta (black sandshell)	L
Ligumia subrostrata (pondmussel)	T
Megalonaias nervosa (washboard)	XT
Obliquaria reflexa (threehorn wartyback)	L
Obovaria olivaria (hickorynut)	L
Obovaria retusa (ring pink)	X
Obovaria subrotunda (round hickorynut)	XT
Plethobasus cicatricosus (white wartyback)	X
Plethobasus cooperianus (orangefoot pimpleback)	X
Plethobasus cyphyus (sheepnose)	XT
Pleurobema clava (clubshell)	XT
Pleurobema cordatum (Ohio pigtoe)	XT
Pleurobema plenum (rough pigtoe)	X
Pleurobema rubrum (pyramid pigtoe)	X
Pleurobema sintoxia (round pigtoe)	L
Potamilus alatus (pink heelsplitter)	L
Potamilus capax (fat pocketbook)	L
Potamilus ohiensis (pink papershell)	L
Ptychobranchus fasciolaris (kidneyshell)	XT
Pyganodon grandis (giant floater)	L
Quadrula cylindrica cylindrica (rabbitsfoot)	XT
Quadrula fragosa (winged mapleleaf)	X
Quadrula metanevra (monkeyface)	L
Quadrula nodulata (wartyback)	L
Quadrula pustulosa pustulosa (pimpleback)	L
Quadrula quadrula (mapleleaf)	L
Simpsonaias ambigua (salamander mussel)	XT
Strophitus undulatus (creeper)	L
Toxolasma lividus (purple lilliput)	XT
Toxolasma parvus (lilliput)	T
Toxolasma texasiensis (Texas lilliput)	T
Tritogonia verrucosa (pistolgrip)	L
Truncilla donaciformis (fawnsfoot)	L
Truncilla truncata (deertoe)	L
Uniomerus tetralasmus (pondhorn)	T
Utterbackia imbecillis (paper pondshell)	L
Villosa fabalis (rayed bean)	XT
Villosa iris (rainbow)	XT
Villosa lienosa (little spectaclecase)	T

RESULTS AND DISCUSSION

For the purpose of this paper, freshwater mussel species are considered extirpated if they no longer maintain a reproducing population. It is possible remnant live individuals

Table 2.—Summary of status for freshwater mussels in the Wabash River drainage of Indiana.

Status	Number of species
Reproducting populations still found in the mainstem Wabash River and its tributaries	30
Reproducing populations historically found in the mainstem Wabash River but now restricted to its tributaries	18
Reproducing populations always restricted to Wabash River tributaries	9
Extirpated from the entire Wabash River drainage	18
Total species:	75

of some of the species considered extirpated may still be found. However, because their populations have reached levels that no longer support reproduction, they are deemed functionally extirpated. Viable populations refer only to those aggregations of freshwater mussels that are reproducing, as evidenced by the presence of live, young individuals.

Of the 75 species of freshwater mussels historically known from the Wabash River drainage of Indiana, 30 still maintain populations in both the mainstem Wabash River and its tributaries, 18 are extirpated from the mainstem, but maintain populations in some portion of the drainage, and 18 are now extirpated from the entire drainage (Tables 1, 2). The nine remaining species are small-stream species or species of unique habitats and probably never had populations in the mainstem Wabash River; they maintain populations in tributaries of the Wabash River drainage within Indiana.

In describing the distribution of some of the freshwater mussel species in the following discussion, the 'upper Wabash River' is used to describe the area upstream from where Sugar Creek enters the Wabash River in Parke and Vermillion counties. The 'lower Wabash River' refers to the area downstream from Sugar Creek to its confluence with the Ohio River.

Live species of mainstem Wabash River and its tributaries.—Thirty species of freshwater mussels still maintain populations in both the mainstem Wabash River and its tributaries (Table 1). The most widely distributed of these species can be found throughout the entire drainage, in a variety of stream sizes. These species include: threeridge (*Amblema plicata*), Wabash pigtoe (*Fusconaia flava*), plain pocketbook (*Lampsilis cardium*), fatmucket (*Lampsilis siliquoidea*), white heelsplitter (*Lasmigona complanata*), giant floater (*Pyganodon grandis*), and paper pondshell (*Utterbackia imbecillis*). Although common throughout the drainage, these species tend to be less common in the tributaries and mainstem of the extreme lowest section of the Wabash River.

Several species are primarily restricted to the mainstem Wabash River and the lower parts of its largest tributaries. These species include: yellow sandshell (*Lampsilis teres*), fragile papershell (*Leptodea fragilis*), threehorn wartyback (*Obliquaria reflexa*), hickorynut (*Obovaria olivaria*), pink heelsplitter (*Potamilus alatus*), pink papershell (*Potamilus ohiensis*), monkeyface (*Quadrula metanevra*), pimpleback (*Quadrula pustulosa pustulosa*), mapleleaf (*Quadrula quadrula*), pistolgrip (*Tritogonia verrucosa*), fawnsfoot (*Truncilla donaciformis*), and deertoe (*Truncilla truncata*). These species are also the most common inhabitants of the tributaries of the lower Wabash River, where most of the other live species are not found.

Some species are restricted to the tributaries and mainstem of the upper Wabash River and the upper watersheds of its other larger tributaries (East Fork and West Fork White rivers). These species include: mucket (*Actinonaias ligamentina*), elktoe (*Alasmidonta marginata*), wavyrayed lampmussel (*Lampsilis fasciola*), flutedshell (*Lasmigona costata*), round pigtoe (*Pleurobema sintoxia*), and creeper (*Strophitus undulatus*).

Black sandshell (*Ligumia recta*) is restricted to the lower sections of the larger tributaries and mainstem of the upper Wabash River. Purple wartyback (*Cyclonaias tuberculata*) and pocketbook (*Lampsilis ovata*) have similar distributions but are also found in the lower mainstem East Fork White River.

Fat pocketbook (*Potamilus capax*) and wartyback (*Quadrula nodulata*) have the most restricted ranges of these live species. Both are concentrated in the extreme lower section of the mainstem Wabash River. They do ascend some tributaries of the lower mainstem; however, their reproductive success in these areas is somewhat questionable.

Live tributary species extirpated from mainstem Wabash River.—Eighteen freshwater mussel species that once maintained populations throughout the Wabash River drainage are now restricted to populations that are viable only in the tributaries (Table 1). For many of these species, live individuals can be found in the mainstem Wabash River; however, they no longer constitute reproducing populations.

Many species that are now restricted to the tributaries of the Wabash River have been gone from the mainstem for a long time. These species include: butterfly (*Ellipsaria lineolata*), spike (*Elliptio dilatata*), snuffbox (*Epioblasma triquetra*), round hickorynut (*Obovaria subrotunda*), clubshell (*Pleurobema clava*), Ohio pigtoe (*Pleurobema cordatum*), salamander mussel (*Simpsonaias ambigua*), purple lilliput (*Toxolasma lividus*), rayed bean (*Villosa fabalis*), and rainbow (*Villosa iris*). Many of these species are now rare in the tributaries, and most have incurred a substantial reduction in their historic distribution.

Live individuals of the following species can occasionally be found in the mainstem Wabash River; however, all are functionally extirpated and restricted to the tributaries: rock pocketbook (*Arcidens confragosus*), fanshell (*Cyprogenia stegaria*), elephantear (*Elliptio crassidens*), ebonyshell (*Fusconaia ebena*), washboard (*Megalonaias nervosa*), sheepnose (*Plethobasus cyphyus*), kidneyshell (*Ptychobranchus fasciolaris*), and rabbitsfoot (*Quadrula cylindrica cylindrica*).

Of these species, rock pocketbook, elephantear, ebonyshell, and washboard are the most likely to be collected live. Though these species may still maintain small, isolated, reproducing populations somewhere in the mainstem Wabash River, their continued presence is uncertain at best. We are considering them extirpated until further collections are made that can repudiate this claim.

Fanshell, sheepnose, kidneyshell, and rabbitsfoot are much rarer in the mainstem Wabash River than the previously mentioned species. All have been found sporadically in the mainstem in recent years (Cummings et al. 1992; Ball & Schoenung 1996; EnviroScience 2006). Occasional live individuals of these species could be entering the Wabash River from the lower Tippecanoe River where populations of these species remain.

Tributary species.—Nine species are found live in tributaries of the Wabash River drainage (Table 1) and likely never maintained populations in the mainstem Wabash River in Indiana. These species include: slippershell mussel (*Alasmidonta viridis*), flat floater (*Anodonta suborbiculata*), cylindrical papershell (*Anodontoides ferussacianus*), creek heelsplitter (*Lasmigona compressa*), pondmussel (*Ligumia subrostrata*), lilliput (*Toxolasma parvus*), Texas lilliput (*Toxolasma texasiensis*), pondhorn (*Uniomerus tetralasmus*), and little spectaclecase (*Villosa lienosa*). Shell material of these species is occasionally found in the mainstem Wabash River, likely washing in from tributaries.

Slippershell mussel, cylindrical papershell, creek heelsplitter, and lilliput are small-stream species found in the smaller watersheds throughout the Wabash River drainage (except the southwest portion). These species are likely found live in the very upper mainstem Wabash River in Ohio.

Flat floater, pondhorn and Texas lilliput are primarily restricted to the southwest portion of the Wabash River drainage, where they inhabit the ditches, oxbows, and other similar habitats of the region. Pondmussel can be found in this portion of the drainage as well but is also an inhabitant of the natural lakes of the upper Wabash River drainage.

Little spectaclecase is a small- to medium-sized stream species. It has a rather sporadic distribution within the Wabash River drainage. It inhabits tributaries of the middle Wabash, East Fork White, and West Fork White rivers.

Extirpated species.—Eighteen freshwater mussel species are now considered extirpated from the entire Wabash River drainage (Table 1). All 18 species are also extirpated from the entire state of Indiana. These species include: spectaclecase (*Cumberlandia monodonta*), leafshell (*Epioblasma flexuosa*), white catspaw (*Epioblasma obliquata perobliqua*), round combshell (*Epioblasma personata*), Tennessee riffleshell (*Epioblasma propinqua*), Wabash riffleshell (*Epioblasma sampsonii*), northern riffleshell (*Epioblasma torulosa rangiana*), tubercled blossom (*Epioblasma torulosa torulosa*), longsolid (*Fusconaia subrotunda*), cracking pearlymussel (*Hemistena lata*), pink mucket (*Lampsilis abrupta*), scaleshell (*Leptodea leptodon*), ring pink (*Obovaria retusa*), white wartyback (*Plethobasus cicatricosus*), orangefoot pimpleback (*Plethobasus cooperianus*), rough pigtoe (*Pleurobema plenum*), pyramid pigtoe (*Pleurobema rubrum*), and winged mapleleaf (*Quadrula fragosa*). Most of these species have been lost from the fauna for many years, and several are even extinct.

A single live rough pigtoe was collected from the East Fork White River in 1992 (Ball & Schoenung 1996). A single live longsolid was collected from Sugar Creek in 1991 (Lewis 1991). These represent the last known live collections of either species from Indiana waters. If these species are live in the Wabash River drainage they are extremely rare and are no longer reproducing.

Federally-endangered species.—Three federally-endangered freshwater mussel species maintain populations in the Wabash River drainage of Indiana. Clubshell is found throughout the Tippecanoe River in the upper Wabash River drainage. Fanshell is found in the lower Tippecanoe River (below Lake Freeman) and the lower East Fork White River. The fat pocketbook survives in the extreme lowest section of the mainstem Wabash River, where it is one of the most common live freshwater mussels found.

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LITERATURE CITED

Ball, R.L. & B.M. Schoenung. 1996. Status of mussel populations in the primary harvest areas. 1995 final report. Division of Fish and Wildlife, Indiana Department of Natural Resources. Indianapolis. 72 pp.

Blatchley, W.S. & L.E. Daniels. 1903. On some Mollusca known to occur in Indiana. A supplementary paper to Call's catalogue. 26th Annual Report of the Indiana Department of Geology and Natural Resources 26:577–628.

Call, R.E. 1894. A contribution to a knowledge of Indiana Mollusca. Proceedings of the Indiana Academy of Science 9:140–156.

Call, R.E. 1896. Second contribution to a knowledge of Indiana Mollusca. Proceedings of the Indiana Academy of Science 11:135–146.

Call, R.E. 1897. The hydrographic basins of Indiana and their molluscan fauna. Proceedings of the Academy of Science 12:247–257.

Call, R.E. 1900. A descriptive illustrated catalogue of the Mollusca of Indiana. 24th Annual report of the Indiana Department of Geology and Natural Resources 24:335–535+.

Clark, C.F. 1976. The freshwater naiads of the lower end of the Wabash River, Mt. Carmel, Illinois to the south. Sterkiana 61:1–14.

Clarke, A.H., P. Hovingh & J.J. Clarke. 1999. A freshwater mussel inventory of four tributary watersheds of the East Fork White River, Hoosier National Forest, Indiana, with notes on other freshwater mollusks and on amphibians and leeches. Final Report to the United States Department of Agriculture, U.S. Forest Service, Hoosier National Forest, Brownstown Ranger District. Bedford, Indiana. 33+ pp.

Commonwealth Biomonitoring. 2005. Bioassessment in the Tippecanoe River watershed 2003 and 2004. Final Report to the Nature Conservancy—Indiana Chapter. 14+ pp.

Cummings, K.S. & J.M.K. Berlocher. 1990. The naiades or freshwater mussels (Bivalvia: Unionidae) of the Tippecanoe River, Indiana. Malacological Review 23:83–98.

Cummings, K.S. & C.A. Mayer. 1997. Distributional checklist and status of Illinois freshwater mussels (Mollusca: Unionacea). Pp. 129–145, *In* Conservation and management of freshwater mussels II: Initiatives for the future. (K.S. Cummings, A.C. Buchanan, C.A. Mayer & T.J. Naimo, eds.). Proceedings of a UMRCC symposium, 16–18 October 1995, St. Louis, Missouri. Upper Mississippi River Conservation Committee, Rock Island, Illinois.

Cummings, K.S., C.A. Mayer & L.M. Page. 1992. Survey of the freshwater mussels (Mollusca: Unionidae) of the Wabash River drainage. Final Report. Final Report to the Nongame and Endangered Wildlife Program, Division of Fish & Wildlife, IDNR. Indianapolis. 201 pp.

Daniels, L.E. 1903. A check list of Indiana Mollusca, with localities. 27th Annual Report of the Indiana Department of Geology and Natural Resources. 27:629–652.

Daniels, L.E. 1915. A supplemental check list of Indiana Mollusca, with localities and notes. 39th Annual Report of the Indiana Department of Geology and Natural Resources 39:318–326.

Ecological Specialists, Inc. 1993. Mussel habitat suitability and impact analysis of the Tippecanoe River. Final Report to the Nongame and Endangered Wildlife Program, Division of Fish & Wildlife, IDNR. Indianapolis. 102+ pp.

Ecological Specialists, Inc. 1995. Draft report: a unionid status and distributional survey in the Salamonie and Mississinewa rivers. Final Report to the Nongame and Endangered Wildlife Program, Division of Fish & Wildlife, IDNR. Indianapolis. 44 pp.

Ecological Specialists, Inc. 1998. Unionid survey upstream and downstream of 16 point sources in the Tippecanoe River. Final Report to the U.S. Fish and Wildlife Service, Bloomington Field Office. 90 pp.

Ecological Specialists, Inc. 2001. Unionid mussel survey of the Patoka River, Indiana. Final Report to the U.S. Fish and Wildlife Service, Patoka River National Wildlife Refuge. 22+ pp.

EnviroScience, Inc. 2006. Unionid Survey of the East Fork White River, Tippecanoe River, and Wabash River. Final Report to the Division of Fish and Wildlife, Indiana Department of Natural Resources. Indianapolis. 60+ pp.

Frankland, L. 1996. Survey of the freshwater mussel population of the mainstem of the Wabash River. Boundary River Program, Illinois Department of Conservation. Springfield, Illinois. 8+ pp.

Goodrich, C. & H. van der Schalie. 1944. A revision of the Mollusca of Indiana. The American Midland Naturalist 32:257–326.

Harmon, J.L. 1998. Finalization of freshwater mussel (Bivalvia: Unionidae) survey of Indiana's East Fork White River drainage. Final Report to the Nongame and Endangered Wildlife Program, Division of Fish & Wildlife, IDNR. Indianapolis. 167 pp.

Henschen, M.T. 1987. The freshwater mussels (Unionidae) of the Eel River of northern Indiana. Final Report to the Nongame and Endangered Wildlife Program, Division of Fish & Wildlife, IDNR. Indianapolis. 73 pp.

Henschen, M.T. 1990. The freshwater mussels of the Middle Fork Wildcat Creek Indiana. Final Report to the Nongame and Endangered Wildlife Program, Division of Fish & Wildlife, IDNR. Indianapolis. 16 pp.

Henschen, M.T. 1993. The freshwater mussels (Bivalvia: Unionidae) of Fall Creek, Indianapolis, Indiana from Geist Reservoir to 46th Street. Final Report to the Nongame and Endangered Wildlife Program, Division of Fish & Wildlife, IDNR. Indianapolis. 11 pp.

Henschen, M.T. 1995. Addendum to: The freshwater mussels (Bivalvia: Unionidae) of Fall Creek, Indianapolis, Indiana from Geist Reservoir to 46th Street. Final Report to the Nongame and Endangered Wildlife Program, Division of Fish & Wildlife, IDNR. Indianapolis. 3 pp.

Krumholz, L.A., R.L. Bingham & E.R. Meyer. 1970. A survey of the commercially valuable mussels of the Wabash and White Rivers of Indiana. Proceedings of the Indiana Academy of Science 79:205–226.

Lewis, R.B. 1991. Freshwater mussel (Mollusca: Unionidae) survey of Sugar Creek in Parke, Montgomery, Boone, and Clinton counties of Indiana. Final Report to the Nongame and Endangered Wildlife Program, Division of Fish & Wildlife, IDNR. Indianapolis. 22+ pp.

Meyer, E.R. 1968. The distribution and abundance of freshwater mussels of the family Unionidae (Pelecypoda) of the Wabash, White, and East Fork of the White rivers of Indiana. Final Report to the Division of Fish and Game, Indiana Department of Natural Resources. Indianapolis. 68 pp.

Myers-Kinzie, M.L., S.P. Wente & A. Spacie. 2001. Occurrence and distribution of freshwater mussels in small streams of Tippecanoe County, Indiana. Proceedings of the Indiana Academy of Science 110:141–150.

Page, L.M., K.S. Cummings, C.A. Mayer, S.L. Post & M.E. Retzer. 1992. Biologically significant Illinois streams. An evaluation of the streams of Illinois based on aquatic biodiversity. Final Report to the Illinois Department of Conservation and Illinois Department of Energy and Natural Resources. Springfield, Illinois. 485 pp.

Stein, F. 1881. Synopsis of the molluscous fauna of Indiana. Second Annual Report of the Department of Statistics and Geology for the Year 1880. 2:451–467.

Strayer, D.L. & D.R. Smith. 2003. A Guide to Sampling Freshwater Mussel Populations. American Fisheries Society Monograph 8. American Fisheries Society. Bethesda, Maryland. 103 pp.

Szafoni, R.E., K.S. Cummings & C.A. Mayer. 2000. Freshwater mussels (Mollusca: Unionidae) of the Middle Branch, North Fork Vermilion River, Illinois/Indiana. Transactions of the Illinois State Academy of Science 93(3):229–237.

Tiemann, J.S. 2005. Freshwater mussel (Bivalvia: Unionidae) survey of the Brouilletts Creek basin in Illinois and Indiana. Proceedings of the Indiana Academy of Science 114(1):33–42.

Turgeon, D.D., J.F. Quinn, Jr., A.E. Bogan, E.V. Coan, F.G. Hochberg, W.G. Lyons, P.M. Mikkelsen, R.J. Neves, C.F.E. Roper, G. Rosenberg, B. Roth, A. Scheltema, F.G. Thompson, M. Vecchione & J.D. Williams. 1998. Common and Scientific Names of Aquatic Invertebrates from the United States and Canada: Mollusks, 2nd edition. American Fisheries Society, Special Publication 26. Bethesda, Maryland. 359 pp.

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AN ANNOTATED LIST OF THE AQUATIC INSECTS COLLECTED IN 2004 IN THE WABASH RIVER WATERSHED, INDIANA

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ABSTRACT. In 2004 the Indiana Department of Environmental Management (IDEM) biologists sampled 47 streams and rivers within the Wabash River watershed. More than 5500 aquatic insect specimens, representing 229 taxa from nine orders, 61 families, and 167 genera were collected. Diptera (73 taxa) was the most diverse insect order followed by Coleoptera (43 taxa), Odonata (31 taxa), Ephemeroptera (25 taxa), Trichoptera (23 taxa), Hemiptera (20 taxa), Plecoptera (7 taxa), Megaloptera (5 taxa), and Lepidoptera (2 taxa). We collected 50–70% of the families, 21–45% of the genera, and 9–17% of the species of Ephemeroptera, Odonata, Plecoptera, and Trichoptera currently reported from Indiana. The upper Wabash sub-watershed had the greatest number of insect taxa (148) while the lower Wabash sub-watershed had the fewest taxa (119). Based on rank abundance, *Cheumatopsyche* spp., *Calopteryx maculata*, *Polypedium* spp., *Caenis* spp., *Stenelmis* spp., *Cricotopus/Orthocladius* group, *Tanytarsus* spp., *Ceratopsyche cheilonis*, and *Thienemannimyia* group were found at more than 50% of the sites.

Keywords: Wabash River, environmental quality, macroinvertebrate, IDEM, probabilistic, multi-habitat

For nearly 100 years aquatic macroinvertebrates have been used as indicators of water quality (Forbes 1928; Pantle & Buck 1955). In the 1970s American scientists shifted the focus of biomonitoring from using qualitatively collected indicator species to the use of quantitative sampling and analysis by means of various diversity indices (Bode 1988; Hilsenhoff 1982, 1987, 1988). In order to calibrate and validate indicator organism indices, basic information about distribution and taxonomy is needed. For many areas this information exists at the order or family level; but, other than large checklists, little information exists at the species or lowest taxonomic level (Helenthal et al. 2003).

In 1990, the Indiana Department of Environmental Management (IDEM) initiated a benthic macroinvertebrate community assessment program (IDEM 2001) based on the EPA RBP II protocols (Plafkin et al. 1989). This method utilized a single habitat for assessing rivers and streams using family-level taxonomic resolution. Recent comparisons of family-level versus genus- and species-level identifications of macroinvertebrates has determined that, in most situations, genus- and species-level identifications provide much greater diagonostic resolution (Lenat & Resh 2001). Later, in 2004, IDEM began the development of a multi-habitat (MHAB) sampling method for collecting benthic macroinvertebrates that would incorporate genus- and species-level identifications (IDEM 2006).

The purpose of the present study is to provide a list of aquatic insect taxa collected within the Wabash River watershed, and present a comparison of taxonomic occurrence in four sub-watersheds based on samples collected in 2004. This effort is based on a stratified random sampling approach that reflects representative occurrence in the area.

METHODS

Study area.—The Wabash River, the second largest tributary to the Ohio River, originates near St. Henry, Ohio and flows in a southwesterly direction for 765 km before entering the Ohio River 18 km southwest of Mt. Vernon, Indiana. The Wabash River watershed encompasses 85,236 km^2, with nearly 74% (62,693 km^2) located in Indiana (Illinois and Ohio contribute 21,805 km^2 and 738 km^2, respectively) (Hoggatt 1975). Major streams within the Wabash watershed include the Tippecanoe River, Wildcat Creek, Mississinewa River, Salamonie River, Patoka River, Driftwood River, Flatrock River, Muscatatuck River, and the White River.

The Wabash River watershed is located primarily within the Eastern Corn Belt Plain Ecoregion with the extreme northern area being in the Southern Michigan/Northern Indiana Till Plain Ecoregion, the southcentral area being in the Interior Plateau and Eastern Corn Belt Plain Ecoregion, and the southwestern area being found in the Interior River Lowland Ecoregion. The Eastern Corn Belt Plain and Southern Michigan/Northern Indiana Till Plain Ecoregions are formerly glaciated with bedrock composed of Paleozoic shale, sandstone, limestone and dolomite overlain with clay and loam till and outwash. The Interior River Lowland is composed of both formerly glaciated and un-glaciated areas with bedrock composed of Pennsylvanian shale, sandstone, limestone and coal overlain by Quaternary alluvium and glacial outwash. The Interior Plateau Ecoregion, which was never glaciated, is an area with Quaternary loess, colluvium and alluvium underlain with Mississippian and Pennsylvanian shale, sandstone, and limestone (Woods et al. 1998). About 65% of the Wabash River watershed, primarily within the Eastern Corn Belt Plain and the Northern Indiana Till Plain Ecoregions, is utilized as agricultural cropland for corn and soybean production. Agriculture is also a primary land use within the Interior River Lowland Ecoregion, although oil wells and coal mines are also common. Forests account for 13.5% of the Wabash River watershed and are mostly found within the Interior Plateau Ecoregion (Gammon 1994; Woods et al. 1998).

Study design.—As part of the IDEM Surface Water Monitoring Strategy (2001, 2006), IDEM biologists sampled 47 sites within the Wabash River Watershed during 2004 (Table 1, Fig. 1). Site selection for this study was part of a watershed-based, statewide stratified, random subset of 736 previously sampled macroinvertebrate sampling sites. This study presents a comprehensive phylogenetic taxonomic list of species collected across the Indiana portion of the Wabash River watershed. For the purpose of this study, the Wabash River watershed was divided into four sub-watersheds based on the Monitoring Strategy Areas used by the IDEM Surface Water Monitoring Strategy (2001, 2006). The sub-watersheds are as follows: the upper Wabash River (UWR), lower Wabash River (LWR), West Fork of the White River (WFWR) and East Fork of the White River (EFWR) (Fig. 1).

Numerical classification analysis was conducted using STATISTICA for Windows (StatSoft 2002). We analyzed the 30 most commonly ranked taxa occurring in the entire Wabash River watershed and each of its four sub-watersheds. This information is presented in a cumulative frequency-distribution table of the most common taxa (Table 2).

Field collection.—Aquatic macroinvertebrate samples were collected at each site upstream of bridges (if present) to decrease any effects that the bridges might have on the downstream fauna. Following a modified D-frame dipnet method (IDEM 2001, 2006) described from Plafkin et al. (1989) and Barbour et al. (1999), a one-minute kick sample was taken within a riffle (if available), run, or a typical glide area at each site. In addition, a 50 m length of stream habitat was sampled with a D-frame dipnet to obtain a MHAB sample. Instream habitats included emergent vegetation, submerged macrophytes, depositional zones, logs, sticks, rootwads, rootmats, cobble, and sand. All habitats were sampled as encountered. The MHAB sample and the kick sample were combined and elutriated a minimum of five times through a 50 μm sieve. The contents of the sieve were emptied into a tray and picked through for 15 min, collecting at least 100 organisms per site, obtaining the greatest diversity of organisms possible. Aquatic macroinvertebrates were preserved in 80% isopropyl alcohol and returned to the lab to be processed and identified, usually to genus or species, using regionally-recognized taxonomic references (such as Merritt & Cummins 1996; Hilsenhoff 1995; and Brigham et al. 1982). All specimens were retained and are maintained at the IDEM Shadeland office/laboratory, Indianapolis, Indiana.

RESULTS AND DISCUSSION

This single year sampling effort of 47 sites in the Wabash River watershed collected more than 5500 aquatic insects. Using a MHAB sampling approach a total of 229 aquatic insect taxa, distributed over nine orders, 61 families, and 167 genera was collected (Table 3). The most diverse insect orders were Diptera

Table 1.—Site localities of all sites sampled in the Wabash River watershed, Indiana, in 2004. Site numbers correspond to Table 3 and are shown in Fig. 1.

Site	County	Locality	Latitude N	Longitude W
Upper Wabash River sub-watershed				
A1	Tippecanoe	Wildcat Creek @ Wolfe Rd	40° 27.17′	86° 43.59′
A2	Carroll	Wildcat Creek @ US 421	40° 27.52′	86° 38.13′
A3	Carroll	Wildcat Creek @ CR 50 E	40° 28.58′	86° 30.43′
A4	Carroll	Little Deer Creek @ CR 300 N	40° 35.24′	86° 28.04′
A5	Carroll	Deer Creek @ CR 300 N	40° 35.23′	86° 37.18′
A6	Carroll	Deer Creek U/S of Delphi, Indiana	40° 35.10′	86° 40.08′
A7	Carroll	Deer Creek D/S of Delphi Water Treatment Plant	40° 34.28′	86° 40.59′
A8	White	Honey Creek @ CR 225 N	40° 47.05′	86° 47.39′
A9	Pulaski	Tippecanoe River @ Pulaski	40° 58.22′	86° 39.35′
A10	Pulaski	Mud Creek @ SR 119	40° 59.01′	86° 38.51′
A11	Starke	House Ditch @ CR 850 S	41° 10.44′	86° 32.26′
A12	Fulton	Mill Creek @ CR 250 N (Olson Rd)	41° 05.30′	86° 13.53′
A13	Wabash	Eel River U/S Wabash Rd	40° 59.38′	85° 46.55′
A14	Huntington	Wabash River D/S Huntington Reservoir	40° 50.46′	85° 28.16′
A15	Wells	Eightmile Creek @ Aboite Rd	40° 54.53′	85° 19.09′
A16	Jay	Wabash River @ CR 215 E	40° 34.05′	84° 50.55′
A17	Delaware	Mississinewa River 200m D/S of CR 700 N	40° 17.33′	85° 18.47′
Lower Wabash River sub-watershed				
B1	Knox	Snapp Creek 30m D/S of Iron Bridge	38° 42.04′	87° 29.57′
B2	Knox	Smalls Creek @ ford W of RR, Sec 26	38° 45.06′	87° 29.16′
B3	Knox	Maria Creek @ CR 1050 S	38° 52.53′	87° 20.48′
B4	Sullivan	Sulphur Creek @ SR 48	39° 11.13′	87° 16.15′
B5	Montgomery	Sugar Creek @ CR 600 E	40° 06.28′	86° 47.38′
B6	Warren	Big Pine Creek @ SR 55	40° 18.14′	87° 15.47′
B7	Warren	Mud Pine Creek @ CR 850 N	40° 26.24′	87° 21.30′
West Fork White River sub-watershed				
C1	Greene	Buck Creek @ SR 54, E of Linton	39° 02.17′	87° 06.31′
C2	Clay	Wabash and Erie Canal @ CR 113 W	39° 11.54′	87° 08.09′
C3	Owen	Little Mill Creek @ CR 25 E	39° 21.32′	86° 45.50′
C4	Morgan	Lambs Creek @ Middle Patton Lake Rd	39° 28.10′	86° 30.23′
C5	Hendricks	East Fork White Lick Creek @ CR 800 S	39° 38.46′	86° 20.48′
C6	Putnam	Big Walnut Creek D/S Wildwood Bridge	39° 42.11′	86° 47.24′
C7	Putnam	Plum Creek @ CR 500 N	39° 43.53′	86° 46.04′
C8	Hamilton	Stony Creek @ Cumberland Rd Gaging Station	40° 01.44′	85° 59.42′
C9	Madison	Pipe Creek U/S Alexandria, in WWTP	40° 15.47′	85° 42.00′
C10	Randolph	West Fork White River 120 m U/S CR 1100 W	40° 09.59′	85° 11.11′
East Fork White River sub-watershed				
D1	Orange	Lost River @ Potato Rd	38° 38.11′	86° 21.57′
D2	Lawrence	Guthrie Creek @ Leesville/ Fort Ritner Rd	38° 48.08′	86° 17.43′
D3	Lawrence	Pleasant Run Creek @ CR 50 E	38° 54.01′	86° 28.10′
D4	Lawrence	Wolf Creek @ CR 825 N	38° 58.35′	86° 28.40′
D5	Lawrence	Henderson Creek @ CR off of SR 446	38° 57.43′	86° 22.08′
D6	Jennings	Otter Creek @ CR 190 E, Cherry Park Rd	38° 59.20′	85° 34.31′
D7	Jennings	Leatherwood Creek @ CR 925 N at Zenas	39° 07.03′	85° 28.21′
D8	Jennings	Vernon Fork Muscatatuck River @ CR 1225 N	39° 09.53′	85° 27.45′
D9	Shelby	Lewis Creek @ SR 252	39° 21.49′	85° 51.29′
D10	Johnson	Sugar Creek @ CR 650 S at old CCC Dam	39° 22.52′	86° 00.21′
D11	Shelby	Brandywine Creek @ SR 9	39° 41.13′	85° 46.26′
D12	Rush	Little Blue River @ CR 300 N	39° 39.18′	85° 34.15′
D13	Henry	Big Blue River @ CR 400 S	39° 52.26′	85° 26.20′

Table 2.—Percent occurrence of the 30 most common aquatic insects collected in the Wabash River watershed, Indiana, and its sub-watersheds in 2004. UWR = upper White River sub-watershed, LWR = lower White River sub-watershed, WFWR = West Fork White River sub-watershed, EFWR = East Fork White River sub-watershed.

Taxa	Entire Wabash watershed (N=47)	UWR (n=17)	LWR (n=7)	WFWR (n=10)	EFWR (n=13)
Cheumatopsyche spp.	72	71	57	80	77
Calopteryx maculata	66	53	86	60	77
Polypedilum spp.	60	82	86	60	15
Caeinis spp.	55	29	71	60	77
Stenelmis spp.	55	53	43	70	54
Cricotopus/Orthocladius grp.	53	59	57	60	38
Tanytarsus spp.	53	59	57	60	38
Ceratopsyche cheilonis	53	65	43	60	38
Thienemannimyia grp.	51	47	57	40	62
Enallagma divagans	49	47	57	70	31
Tipula spp.	43	18	14	50	85
Isonychia spp.	43	41	29	40	54
Microtendipes spp.	43	53	43	30	38
Tricorythodes spp.	43	65	43	40	15
Peltodytes duodecimpunctatus	38	41	29	40	38
Dubiraphia spp.	36	29	43	40	38
Boyeria vinosa	34	35	14	50	31
Dicrotendipes spp.	34	29	57	40	23
Argia tibialis	34	41	43	30	23
Baetis intercalaris	34	47	43	30	15
Hydroporus spp.	32	35	29	0	54
Chironomus spp.	32	24	43	30	38
Helichus lithophilus	32	18	57	50	23
Stenonema femoratum	30	6	29	20	69
Microvelia americana	30	6	43	30	54
Peltodytes lengi	30	18	14	40	46
Ceratopsyche spp.	30	35	14	40	23
Dubiraphia minima	30	35	14	40	23
Cladotanytarsus spp.	30	29	43	40	15
Cricotopus trifascia	30	35	43	30	15

(73 taxa), Coleoptera (43 taxa), and Odonata (31 taxa). The remaining 82 taxa were distributed among the orders Ephemeroptera (25 taxa), Trichoptera (23 taxa), Hemiptera (20 taxa), Plecoptera (7 taxa), Megaloptera (5 taxa), and Lepidoptera (2 taxa).

Hellenthal et al. (2003) published a list of 2307 aquatic insect species either recorded from Indiana or likely to occur within the state. The data collected from the Wabash River watershed are presented and compared with this list in Table 4. This study collected 50–70% of the families, 21–45% of the genera, and 9–17% of the species of Ephemeroptera, Odonata, Plecoptera, and Trichoptera currently reported from Indiana (Table 4) (Hellenthal et al. 2003). These are surprisingly high numbers considering the temporal and spatial limits of this study, which sampled only 47 sites in Indiana's largest watershed from September to November.

Diversity by subwatershed.—The UWR sub-watershed had the greatest number of insect taxa (148) while the LWR sub-watershed had the fewest taxa (119). The WFWR and the EFWR had 122 taxa and 132 taxa, respectively. The greatest number of taxa (48) was found in both the LWR sub-watershed in Sugar Creek, Montgomery County (site B5), and within the EFWR sub-watershed, in Brandywine Creek, Shelby County (site D11). The fewest taxa (9) were found in Wolf Creek, Lawrence County (site D4). The average number of taxa collected in the Wabash River wa-

Table 3.—Aquatic insects collected in the Wabash River watershed, Indiana, in 2004. Orders are arranged phylogenetically, followed by the alphabetical listing of families, genera, and species. Numbers associated with each taxon correspond to the site localities listed in Table 1 and shown in Fig. 1.

Order Ephemeroptera (10 families)
  Family Baetidae
    Acentrella turbida (McDunnough): A6, A7, A13, B5, B7, C6
    Baetis spp.: B6, D1
    Baetis flavistriga McDunnough: A1, A2, A4, A6, A7, A13, A15, B7, C7, C10
    Baetis intercalaris McDunnough: A1, A3, A6, A7, A9, A13, A15, A16, B1, B2, B7, C1, C4, C5, D11, D13
    Callibaetis spp.: B2, C8
    Procloeon spp.: A2, C3, C5, C6
  Family Baetiscidae
    Baetisca lacustris McDunnough: D9
  Family Caenidae
    Caenis spp.: A8, A9, A12, A15, A17, B1, B2, B5, B6, B7, C1, C2, C3, C4, C6, C10, D1, D2, D3, D6, D7, D8, D9, D10, D11, D12
  Family Ephemerellidae
    Eurylophella spp.: D1, D5
  Family Ephemeridae
    Ephemera simulans Walker: A17, B5, B6, D2
    Hexagenia limbata (Serville): A9, D9
  Family Heptageniidae
    Leucrocuta hebe (McDunnough): A1, A5, A6, A7, A12, A15, A17, B6, B7, C5, D11
    Mccaffertium spp.: A1, A5, A6, A7, B6, C6
    Mccaffertium mediopunctatum (McDunnough): A4, A5, A6, A7, B6, B7, C6, D10, D11, D12
    Mccaffertium pulchellum (Walsh): A5, A7, A13, A16, A17, B5, B6, C10, D1, D6, D9, D10
    Mccaffertium terminatum (Walsh): A3, A5, A6, A7, A9, A17, B6, C6, D10
    Stenacron spp.: A17, B1
    Stenacron interpunctatum (Say): A4, A5, A6, A7, A8, A9, A15, B2, C1, C2, C4, C6, D2
    Stenonema femoratum (Say): A15, B6, B7, C3, C4, D1, D2, D3, D4, D5, D6, D7, D8, D9
  Family Isonychiidae
    Isonychia spp.: A1, A2, A3, A5, A6, A7, A17, B6, B7, C4, C6, C7, C10, D2, D6, D7, D9, D10, D11, D12
  Family Leptohyphidae
    Tricorythodes spp.: A1, A2, A3, A4, A5, A6, A7, A9, A13, A14, A16, B5, B6, B7, C5, C6, C8, C10, D10, D11

Table 3.—Continued.

  Family Leptophlebiidae
    Leptophlebia cupida (Say): D1, D2, D3, D7, D10
    Paraleptophlebia ontario (McDunnough): A9
  Family Potamanthidae
    Anthopotamus spp.: C6
    Anthopotamus myops (Walsh): A3, A17, B5, D10
Order Odonata (7 families)
  Family Calopterygidae
    Calopteryx maculata (Beauvois): A4, A6, A8, A9, A10, A11, A12, A13, A17, B2, B3, B4, B5, B6, B7, C2, C3, C4, C5, C7, C8, D1, D2, D3, D4, D7, D8, D9, D11, D12, D13
    Hetaerina americana (Fabricius): A4, A6, C2, C5, C8, D11
  Family Coenagrionidae
    Argia spp.: A12, A16, B6, B7, C1, C2, C4, D1, D4
    Argia apicalis (Say): A4
    Argia fumipennis (Burmeister): A4, A8, B5, C2, C8, D7
    Argia moesta (Hagen): A3, A5, A6, A7, A17, B5, B6, B7, C8, D1, D2, D6, D8
    Argia sedula (Hagen): C1, C2
    Argia tibialis (Rambur): A2, A3, A4, A8, A12, A13, A16, B3, B5, B6, C1, C6, C10, D9, D10, D11
    Enallagma spp.: C1, C4
    Enallagma divagans Selys: A2, A4, A6, A7, A8, A9, A12, A16, B1, B2, B4, B5, C1, C2, C4, C5, C6, C8, C10, D1, D9, D10, D11
    Ischnura spp.: C1
    Ischnura posita (Hagen): A8, A9, A11, A16, B4
    Ischnura verticalis (Say): A8, A11, A16
  Family Aeshnidae
    Anax junius (Drury): A8, C2
    Basiaeschna janata Say: B3, C4, D1, D2, D8
    Boyeria vinosa (Say): A2, A6, A9, A10, A12, A13, B5, C2, C3, C5, C7, C10, D7, D9, D10, D13
    Nasiaeschna pentacantha (Rambur): C2
  Family Corduliidae
    Somatochlora spp.: D7
  Family Libellulidae
    Libellula spp.: C2
    Plathemis lydia (Drury): A8, B2, C4
    Sympetrum obtrusum (Hagen): D2
  Family Macromiidae
    Macromia spp.: A5, A9, B5, D6, D9, D10, D11
    Macromia illinoensis Walsh: B5, D9

Table 3.—Continued.

Family Gomphidae
Dromogomphus spinosus Selys: A4, B2, D1, D9, D10
Dromogomphus spoliatus (Hagen in Selys): A2, A3, A6, A9, B5, B6, B7, C5, D2, D8, D9, D10
Erpetogomphus designatus Hagen in Selys: A1, A9
Hagenius brevistylus Selys: C3
Ophiogomphus rupinsulensis (Walsh): A6
Progomphus obscurus Rambur: C4
Stylogomphus sigmastylus Cook and Laudermilk: C3
Stylurus spiniceps (Walsh): A9, D10

Order Plecoptera (4 families)

Family Nemouridae
Shipsa rotunda (Claassen): D10

Family Perlidae
Acroneuria abnormis (Newman): A9
Agnetina flavescens Walsh: D1
Perlinella drymo (Newman): A7, B6, D5, D10, D11

Family Perlodidae
Isoperla spp.: D2, D5

Family Taeniopterygidae
Taeniopteryx spp.: A1, A2, A9, D6, D10, D12
Taeniopteryx metequi Ricker and Ross: D10

Order Hemiptera (8 families)

Family Belostomatidae
Belostoma fluminea Say: A2, A4, A5, A8, A11, A13, A16, C2, C4, D4, D7, D11

Family Corixidae
Hesperocorixa spp.: D11
Sigara spp.: A8, A10, A11, B7, C7, C9, C10, D1, D11
Trichocorixa calva (Say): A2, A8, A11, A16, B2, C8, C10, D1, D3, D6, D11

Family Gerridae
Aquarius spp.: A11, A12, B2, B4, D5
Gerris spp.: A16, B2, B3, B4, C7, D5
Metrobates hesperius Uhler: A6, B5, C5
Rheumatobates spp.: A2, A4, C2, C5
Trepobates inermis-knighti grp.: C4, C6
Trepobates pictus (Herrich-Schaeffer): B1, B3, C1
Trepobates subnitidus Esaki: B2, C2, C3

Family Mesoveliidae
Mesovelia mulsanti White: A12, C4

Family Nepidae
Ranatra fusca Palisot: A2, A8, A13

Family Notonectidae
Notonecta irrorata Uhler: A11, B3, B4, C10

Table 3.—Continued.

Family Pleidae
Neoplea striola (Fieber): A2, B2, C5

Family Veliidae
Microvelia spp.: C7
Microvelia americana (Uhler): A12, B2, B3, B4, C3, C4, C7, D3, D4, D5, D7, D8, D9, D12
Rhagovelia spp.: A16, C6
Rhagovelia obesa Uhler: A13, A16, A17, B6
Rhagovelia oriander Parshley: A4, A9, A10, A17, B5, B6, B7, C3, C4, C5, C6

Order Megaloptera (2 families)

Family Corydalidae
Corydalus cornutus (Linnaeus): A17, B7, D2, D6, D7, D10
Chauliodes pectinicornis (Linnaeus): B2
Nigronia fasciatus (Walker): D3
Nigronia serricornis (Say): C3, D1, D3, D5, D6, D7, D8

Family Sialidae
Sialis spp.: B4, C1, C8, C10, D1, D2, D9, D12

Order Trichoptera (9 families)

Family Brachycentridae
Brachycentrus numerosus (Say): A9

Family Hydropsychidae
Ceratopsyche spp.: A1, A3, A4, A5, A6, A15, B5, C4, C6, C7, C10, D10, D11, D13
Ceratopsyche bronta (Ross): A5, A6, A7, B6, B7, C5, C10, D6, D9, D10, D12
Ceratopsyche cheilonis (Ross): A1, A2, A3, A4, A5, A6, A7, A9, A13, A14, A17, B5, B6, B7, C5, C6, C7, C8, C9, C10, D6, D9, D10, D12, D13
Ceratopsyche sparna (Ross): A10
Cheumatopsyche spp.: A1, A2, A3, A4, A5, A6, A7, A9, A14, A15, A16, A17, B1, B2, B6, B7, C1, C3, C4, C5, C6, C7, C9, C10, D1, D2, D3, D6, D7, D8, D9, D10, D12, D13
Hydropsyche spp.: A1, A8, A9, B2, C8, D11
Hydropsyche aerata Ross: A1, B5
Hydropsyche betteni-depravata group: A4, A8, A10, B2, B3, B7, C4, C8, C9, C10, D3, D11, D13
Hydropsyche dicantha Ross: A1, A3, A5, A6, A16, B7, C10, D13
Hydropsyche frisoni Ross: D11
Hydropsyche simulans Ross: A9, A13, A15, B2, B7

Family Hydroptilidae
Agraylea spp.: A9
Hydroptila spp.: C7

Family Leptoceridae
Nectopsyche exquisita (Walker): A6, A13
Oecetis spp.: A3, A4, B5, D6

Table 3.—Continued.

Family Limnephilidae
Pycnopsyche spp.: A10, D10

Family Philopotamidae
Chimarra aterrima (Hagen): C3, C7, D2, D3
Chimarra obscura (Walker): A1, A2, A3, A6, A7, C1, C4, D2, D6, D7, D8, D12

Family Phyrganeidae
Ptilostomis spp.: A11, A17, B4, D2

Family Polycentropodidae
Cernotina spicata Ross: A17, D9
Neureclipsis crepuscularis (Walker): A4, A9

Family Rhyacophilidae
Rhyacophila lobifera Betten: D2

Order Lepidoptera (1 family)

Family Pyralidae
Crambus spp.: A17, D4
Petrophila spp.: A1, A2, A4, A6, B5

Order Coleoptera (9 families)

Family Carabidae
Stenus spp.: D13

Family Dryopidae
Helichus basalis LeConte: C3, D5, D6, D8
Helichus fastigiatus (Say): D5
Helichus lithophilus (Germar): A4, A5, A7, B1, B2, B5, B6, C1, C3, C4, C6, C7, D4, D8, D9
Helichus striatus LeConte: A10

Family Dytiscidae
Agabus spp.: D5
Copelatus chevrolati Aube: B1
Coptotomus interrogatus (Fabricius): A3
Coptotomus loticus Hilsenhoff: A1, A11, B2
Hydroporus spp.: A1, A2, A3, A8, A11, A16, B2, B4, D1, D2, D3, D4, D5, D7, D8
Ilybius spp.: B4
Laccophilus spp.: B4
Laccophilus fasciatus Aube: B4
Laccophilus maculosus Say: A1, A11, B2, C7, C10, D7
Liodessus affinis (Say): A9, D11

Family Elmidae
Dubiraphia spp.: A1, A2, A7, A8, A10, B1, B2, B5, C1, C8, C9, C10, D1, D7, D9, D10, D11
Dubiraphia minima Hilsenhoff: A2, A3, A4, A6, A13, A16, B5, C1, C2, C4, C5, D9, D10, D11
Macronychus glabratus (Say): A2, A9, A13, B5, C1, C2, C5, C7
Optioservus spp.: A4, A6, A10, D12
Optioservus fastiditus (LeConte): A10
Optioservus trivittatus (Brown): D12

Table 3.—Continued.

Stenelmis spp.: A1, A2, A3, A4, A6, A7, A15, A16, A17, B3, B5, B6, C1, C4, C5, C6, C7, C9, C10, D2, D3, D6, D8, D11, D12, D13
Stenelmis crenata (Say): A4, A15, A17, B5, C1, C2, C5, C7, C10, D2, D3, D8, D11
Stenelmis quadrimaculata Horn: B2
Stenelmis sexlineata Sanderson: A2, A3, A4, A5, A17, B5, C4, C10, D6, D8, D9, D11
Stenelmis vittipennis Zimmerman: A2, A3, A16, B1, B5, D10

Family Gyrinidae
Gyrinus spp.: A10, A11, B4, C2, D9
Gyrinus maculiventris LeConte: D10

Family Haliplidae
Peltodytes duodecimpunctatus (Say): A2, A3, A8, A9, A10, A11, A16, B2, B3, C2, C7, C9, C10, D7, D8, D9, D11, D12
Peltodytes edentulus (LeConte): A3, A8, A16, D9
Peltodytes lengi Roberts: A2, A9, A11, B5, C5, C8, C9, C10, D1, D2, D7, D8, D11, D12
Peltodytes sexmaculatus Roberts: A8, B5, D3, D11

Family Hydrophilidae
Berosus spp.: A1, A2, A4, A8, A14, B6
Berosus fraternus LeConte: B2
Berosus pantherinus LeConte: B2
Enochrus spp.: D9
Helophorus spp.: A3, A16, D11
Hydrobius spp.: C7
Laccobius spp.: C7
Tropisternus glaber (Herbst): B2, B3, C2, D2

Family Psephenidae
Ectropia spp.: D1
Psephenus herricki (De Kay): A17, C3, D1, D2, D3, D4, D6, D7, D8, D9, D11, D12

Family Scirtidae
Cyphon spp.: A2, A9, A10, B3, B5, B6, C1, C4, D2, D5, D7, D11

Order Diptera (11 families)

Family Chironomidae
Subfamily Orthocladiinae
Tribe Corynoneurini
Corynoneura spp.: A4, A6, A17, C7, D2, D7, D9, D11, D12
Thienemanniella spp.: A7
Thienemanniella taurocapita Hestenes and Saether: C7
Theinemanniella xena (Roback): A12, B5

Tribe Orthocladiini/Metriocnemini:
Brillia spp.: A4
Cardiocladius spp.: A3
Cricotopus/Orthocladius spp.: A1, A2, A3, A4, A5, A6, A7, A9, A13, A14, B2, B5,

Table 3.—Continued.

B6, B7, C2, C5, C6, C7, C8, C10, D2, D9, D10, D11, D13
Cricotopus trifascia Edwards: A1, A2, A3, A6, A7, A13, B5, B6, B7, C7, C8, C10, D9, D11
Diplocladius cultiger Kieffer: D2
Eukiefferiella spp.: A3, D10
Hydrobaenus spp.: A17, D7, D11
Nanocladius spp.: A4
Parakiefferiella spp.: A3, A4, A5, A6, A7, A8, B6, B7, C8, D9, D10
Psectrocladius spp.: D11, D13
Rheocricotopus spp.: A13, C3
Tvetnia spp.: A1, A14, C8

Subfamily Chironominae
Tribe Chironomini
Chironomus spp.: A2, A3, A4, A7, B2, B4, B6, C6, C7, C9, D7, D9, D10, D11, D13
Cryptochironomus spp.: A2, A17, B2, B5, B6, B7, C5, C9
Cryptotendipes spp.: B2, C2
Dicrotendipes spp.: A1, A2, A3, A4, A5, B2, B5, B6, B7, C6, C7, C8, C10, D9, D11, D12
Glyptotendipes sp.: B2, C7
Microtendipes spp.: A1, A2, A3, A4, A6, A8, A14, A15, A17, B5, B6, B7, C3, C6, C10, D7, D9, D10, D11, D12
Paracladopelma spp.: B1
Paurolaterborniella nigrohalteralis (Malloch): A3
Paratendipes spp.: B1
Phaenopsectra spp.: A1, A2, A4, A5, A7, A14, B7, C1, C6, D13
Polypedilum spp.: A1, A2, A3, A4, A5, A6, A7, A9, A12, A13, A14, A15, A16, A17, B1, B2, B3, B4, B6, B7, C1, C2, C3, C6, C7, C10, D6, D12
Saetheria spp.: A15, C5, C6
Stictochironomus spp.: A3, A4, A7, A17, B3, C5, D7, D10, D11

Tribe Pseudochironomini
Pseudochironomus spp.: A3

Tribe Tanytarsini
Cladotanytarsus spp.: A3, A5, A6, A7, A15, B1, B6, B7, C4, C5, C6, C7, D9, D11
Neozavrelia spp.: A6
Paratanytarsus spp.: C2, C6, C8, D9, D10
Rheotanytarsus spp.: A1, A6, A8, A14, B5, B6, B7, C6, C7
Stempellinella spp.: A4, A7, B5, B7, C6, D11, D12
Subletta spp.: C6
Subletta coffmani (Roback): A8
Tanytarsus spp.: A1, A2, A3, A4, A5, A6, A7, A13, A14, A17, B1, B2, B5, B7, C1, C4, C6, C7, C8, C10, D9, D10, D11, D12, D13

Table 3.—Continued.

Subfamily Tanypodinae
Tribe Procladiini
Procladius spp.: A12, B2, B5, C7, C9, D10
Tribe Pentanuerini
Ablabesmyia spp.: A12
Ablabesmyia janta (Roback): A3
Ablabesmyia mallochi (Walley): B2, B5, B6, C6, D1
Labrundinia pilosella (Loew): A3, A6, A9, A12, C3, C4, C7
Paramerina spp.: A2, A4, D12
Pentaneura spp.: C7
Telopelopia spp.: A15
Theinenmannimyia group: A2, A5, A6, A12, A13, A14, A15, A17, B2, B5, B6, B7, C5, C6, C7, C9, D2, D6, D7, D8, D9, D11, D12, D13
Zavrelimyia spp.: D8

Tribe Tanypodini
Tanypus neopunctipennis Sublette: B2

Family Athericidae
Atherix spp.: A9

Family Ceratopogonidae
Bezzia-Palpomyia group: D9
Ceratopogon spp.: B5
Dasyhela spp.: D9

Family Culicidae
Anopheles punctipennis (Say): B2, C4, C7
Culex spp.: C1

Family Dixidae
Dixella spp.: C3, C4, D7, D11

Family Empididae
Hemerodromia spp.: A1, A4, A5, A6, A7, A8, A16, B5, B7, C7

Family Simuliidae
Simulium spp.: A3, A6, A15, D10
Simulium jenningsi Malloch: A1, A3, A13, B7, C6
Simulium tuberosum complex: A4, A15, B1, C4
Simulium venustum complex: D6
Simulium vittatum Zetterstedt: A3, A4, A5, A6, A7, A8, A14, A15, B7, C8, C10, D11

Family Stratiomyidae
Nemotelus spp.: D13

Family Syrphidae
Helophilus spp.: D12

Family Tabanidae
Chrysops spp.: A2, A5, A7, A8, A15, B5, C1, C3, C4, C5, C10, D7, D12
Tabanus spp.: B7, C6, D5, D12

Table 3.—Continued.

Family Tipulidae
Antocha spp.: C7, D10
Dicranota spp.: D5
Erioptera spp.: A7, A17
Hexatoma spp.: A12, C4, C5, C7, C10, D2, D5, D12
Pilaria spp.: C10
Pseudolimnophila spp.: B2, D7
Tipula spp.: A4, A10, A17, B7, C1, C7, C8, C9, C10, D1, D2, D3, D6, D7, D8, D9, D10, D11, D12, D13

tershed was 29. Among the individual sub-watersheds, the greatest average number of taxa (31) was in the LWR sub-watershed while the smallest average number of taxa (27) was in the EFWR sub-watershed. The average number of taxa at sites in the UWR and WFWR sub-watersheds was 29.

Rank abundance by site occurrence.—Table 2 presents the 30 most abundant taxa by site occurrence. The most commonly encountered taxon, the Trichoptera genus *Cheumatopsyche* spp., occurred at 72% of all sites (Table 2). Although Hellenthal et al. (2003) reported 11 *Cheumatopsyche* species for Indiana, the larvae of this genus currently cannot be identified to species level. Sampling and identification of adult material using larval-rearing, emergence traps, black-lights or

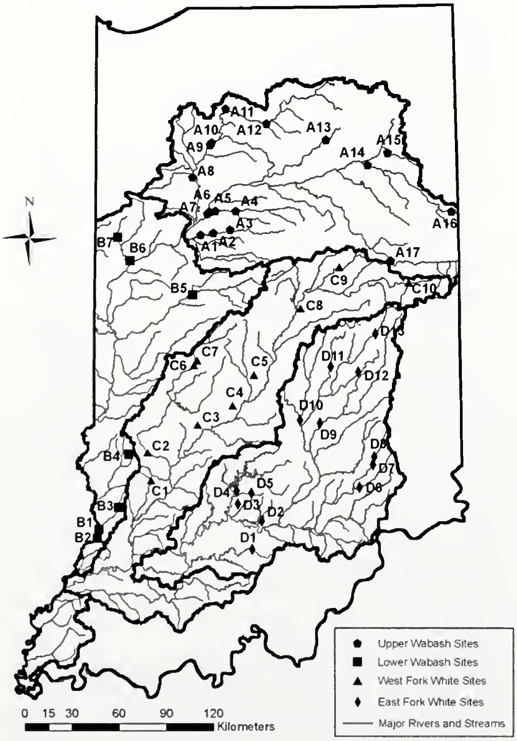

Figure 1.—Map of the Wabash River Watershed in Indiana, showing collection sites sampled in 2004.

Table 4.—Comparison of number of families, genera and species of Ephemeroptera, Odonata, Plecoptera and Trichoptera collected from the Wabash River watershed during the present study to those currently known from Indiana (Hellenthal et al. 2003).

	Families	Genera	Species
Ephemeroptera			
Hellenthal et al. (2003)	16	50	143
Wabash (present study)	10	18	18
% representation	63%	36%	13%
Odonata			
Hellenthal et al. (2003)	10	47	154
Wabash (present study)	7	21	26
% representation	70%	45%	17%
Plecoptera			
Hellenthal et al. (2003)	8	29	71
Wabash (present study)	4	6	6
% representation	50%	21%	9%
Trichoptera			
Hellenthal et al. (2003)	16	58	194
Wabash (present study)	9	14	21
% representation	56%	24%	11%

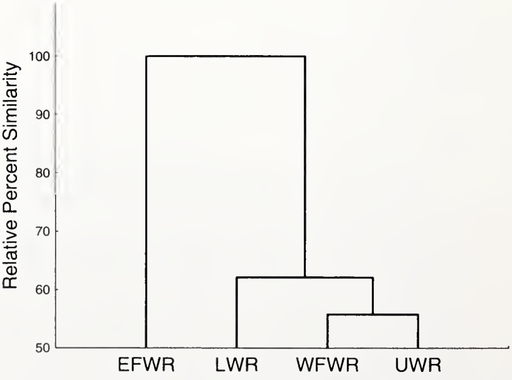

Figure 2.—Numerical classification analysis comparison of top 30 rank occurring aquatic insects by sub-watershed using Euclidean distance similarities. UWR = upper White River sub-watershed, LWR = lower White River sub-watershed, WFWR = West Fork White River sub-watershed, EFWR = East Fork White River sub-watershed.

other such collection methods may be useful for providing species occurrence data for problem insect genera.

Numerical classification analysis.—Numerical classification analysis of the percentage of occurrence of the 30 most common taxa (Table 2) from the four sub-watersheds is presented in Fig. 2. This dendogram shows that sites in the UWR sub-watershed are most compositionally similar to sites within the WFWR. These two sub-watersheds are then most similar to sites in the LWR sub-watershed. The internodal distance between the EFWR and the other sub-watersheds is reflected by a relative difference of 40% (Fig. 2) indicating that this sub-watershed is significantly different in composition and structure. Sobat et al. (2006) reported that the Wabash River (including both UWR and LWR sub-watersheds), the WFWR, and the EFWR fish communities, based on analysis of Index of Biotic Integrity (IBI) scores, have been assessed in the good-to-excellent condition at 14%, 17% and 33%, respectively. This numerical pattern of aquatic insect and fish community data suggested that the EFWR sub-watershed was of a higher environmental quality than the other sub-watersheds within the Wabash River watershed.

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LITERATURE CITED

Barbour, M.T., J. Gerritsen, B.D. Snyder & J.B. Stribling. 1999. Rapid Bioassessment Protocols for Use in Streams and Wadeable Rivers: Periphyton, Benthic Macroinvertebrates and Fish, Second Edition. EPA 841-B-99-002. U.S. Environmental Protection Agency, Office of Water, Washington, D.C.

Bode, R.W. 1988. Quality Assurance Workplan for Biological Stream Monitoring in New York State. New York State Department of Environmental Conservation, Albany, New York. 122 pp.

Brigham, A.R., W.U. Brigham & A. Gnilka (eds.). 1982. Aquatic Insects and Oligochaetes of North and South Carolina. Midwest Aquatic Enterprises, Mahomet, Illinois. 837 pp.

Forbes, S.A. 1928. The biological survey of a river system—its objects, methods and results. Illinois Natural History Survey Bulletin 17:277–284.

Gammon, J.R. 1994. The Wabash River Ecosystem. A Report for PSI-Energy, Plainfield, Indiana and Eli Lilly and Company, Indianapolis, Indiana. 213 pp.

Hellenthal, R.A., R.D. Waltz, A.V. Provonsha & J.D. Haddock. 2003. Preliminary Checklist of Indiana Aquatic Insects. Indiana Academy of Science Aquatic Macroinvertebrates Workshop: Overview of the State of Science. October 17, 2003. Anderson, Indiana. *iv* + 73 pp.

Hilsenhoff, W.L. 1982. Using a Biotic Index to Evaluate Water Quality in Streams. Technical Bulletin No. 132. Department of Natural Resources, Madison, Wisconsin. 22 pp.

Hilsenhoff, W.L. 1987. An improved biotic index of organic stream pollution. Great Lakes Entomologist 20:31–39.

Hilsenhoff, W.L. 1988. Rapid field assessment of organic pollution with a family-level biotic index. Journal of the North American Benthological Society 7:65–68.

Hilsenhoff, W.L. 1995. Aquatic Insects of Wisconsin, Keys to Wisconsin Genera and Notes on Biology, Habitat, Distribution and Species. University of Wisconsin–Madison Natural History Museums Council Publication No. 3, G3648. 79 pp.

Hoggatt, R.E. 1975. Drainage Areas of Indiana Streams. U.S. Department of the Interior Geological Survey, Water Resource Division. 231 pp.

Indiana Department of Environmental Management (IDEM). 2001. IDEM Surface Water Quality Monitoring Strategy 2001–2005. Assessment Branch, Office of Water Quality, Indiana Department of Environmental Management, Indianapolis, Indiana. IDEM/32/01/021, May 2001.

Indiana Department of Environmental Management (IDEM). 2006. Indiana Water Quality Monitoring Strategy 2006–2010. M-001-OWQ-A-00-06-R03. IDEM, Office of Water Quality, Assessment Branch, Indianapolis, Indiana.

Lenat, D.R. & V.H. Resh. 2001. Taxonomy and stream ecology: The benefits of genus- and species-level identifications. Journal of the North American Benthological Society 20:287–298.

Merritt, R.W. & K.W. Cummins (eds.). 1996. An Introduction to the Aquatic Insects of North America. Kendall/Hunt Publishing Company, Dubuque, Iowa. 862 pp.

Pantle, R. & H. Buck. 1955. Die biologische Überwachung der Gewässer und die Daistellung der Ergebnisse. (Biological monitoring of waterbodies and the presentation of results). Gas und Wasserfach 96:604.

Plafkin, J.L., M.T. Barbour, K.D. Porter, S.K. Gross & R.M. Hughes. 1989. Rapid Bioassessment Protocols For Use in Streams and River: Benthic Macroinvertebrates and Fish. EPA 440/4-89/001. U.S. Environmental Protection Agency, Office of Water, Washington D.C.

Sobat, S.L., C.C. Morris, A.K. Stephan & T.P. Simon. 2006. Changes in the condition of the Wabash River drainage from 1990–2004. Proceedings of the Indiana Academy of Science 115: 156–169.

StatSoft. 2002. STATISTICA for Windows. StatSoft, Tulsa, Oklahoma.

Woods, A.J., J.M. Omernik, C.S. Brockman, T.D. Gerber, W.D. Hosteter & S.H. Azevedo. 1998. Ecoregions of Indiana and Ohio. (Map poster). U.S. Geological Survey, Reston, Virginia.

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2006. Proceedings of the Indiana Academy of Science 115(2):121–135

PRESENT AND HISTORIC DISTRIBUTION OF FISHES IN SOUTH FORK WILDCAT CREEK, TIPPECANOE, CLINTON AND TIPTON COUNTIES, INDIANA

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ABSTRACT. The fish fauna of the South Fork Wildcat Creek watershed, Tippecanoe, Clinton, and Tipton counties, was studied at 88 sites to evaluate species diversity and the historical and present distribution of fish assemblages. In 2004, we used a targeted watershed survey design ($n = 80$) to spatially increase extrapolated data coverage produced by a random probability sampling of the Wabash River drainage. Few historic collections have been made in the watershed, with only three sites collected prior to 1950, seven sites from a survey of Tippecanoe County in 1994, and an additional 11 sites from monitoring activities between 1995 and 2003. In all, 73 species have been collected from the South Fork Wildcat Creek watershed, with only 21 species recorded from all sampling events. Dominant species include *Semotilus atromaculatus*, *Campostoma anomalum*, and *Pimephales notatus*. *Etheostoma camurum* and *Luxilus cornutus* have not been collected since the 1945 surveys. However, the absence of *Luxilus cornutus* is likely a result of taxonomic changes that resulted in *Luxilus cornutus* and *Luxilus chrysocephalus* being recognized as separate species. Six species (*Ichthyomyzon unicuspis*, *Lepisosteus osseus*, *Notropis volucellus*, *Notropis wickliffi*, *Pylodictis olivaris*, and *Lepomis microlophus*) have not been collected since 1994. In 2004, an additional 12 species (*Campostoma oligolepis*, *Nocomis biguttatus*, *Notemigonus crysoleucus*, *Phoxinus erythrogaster*, *Carpiodes velifer*, *Carpiodes carpio*, *Ictalurus punctatus*, *Noturus gyrinus*, *Gambusia affinis*, *Lepomis gulosus*, *Poxomis nigromaculatus*, and *Aplodinotus grunniens*) were the first verified records for the watershed.

Keywords: Wabash River drainage, watershed condition, fish assemblage

The Clean Water Act mandates state water quality agencies to restore and protect the surface waters of the nation. Incumbent upon meeting this goal is to have basic information on watersheds of Indiana and other states. Few studies have targeted entire watersheds (Carney et al. 1998; Simon et al. 2005), with most intensive studies focusing on county level investigations such as that of Fisher et al. (1998) for Tippecanoe County. The need to restore and protect the Wabash River begins in the tributary streams. The South Fork Wildcat Creek has been designated by the State of Indiana as an Outstanding State Resource Water; however, Outstanding State status is not based on biological assemblages. As watersheds change due to anthropogenic input, knowledge of the aquatic assemblage is imperative for trend assessment.

No surveys of the South Fork Wildcat Creek watershed exist prior to 1940. The ichthyofauna of this watershed was first examined by Gerking (1945), who collected fish from 412 sites across Indiana (three from the South Fork Wildcat Creek watershed) between 1940 and 1943, and compiled all other historical records known at the time. Fisher et al. (1998) compiled species lists from seven sites in the South Fork Wildcat Creek watershed during sampling in 1994. During 1995, the U.S. Environmental Protection Agency randomly selected sites in an intensive survey of the Eastern Corn Belt Plain. This resulted in six sites being sampled in the South Fork of the Wildcat Creek watershed. The Indiana Department of Environmental Management (IDEM) sampled five sites between 1998 and 2003 as part of the stratified random sampling design for Indiana watersheds (IDEM 1998, 2001). In all, 21 collections were recorded

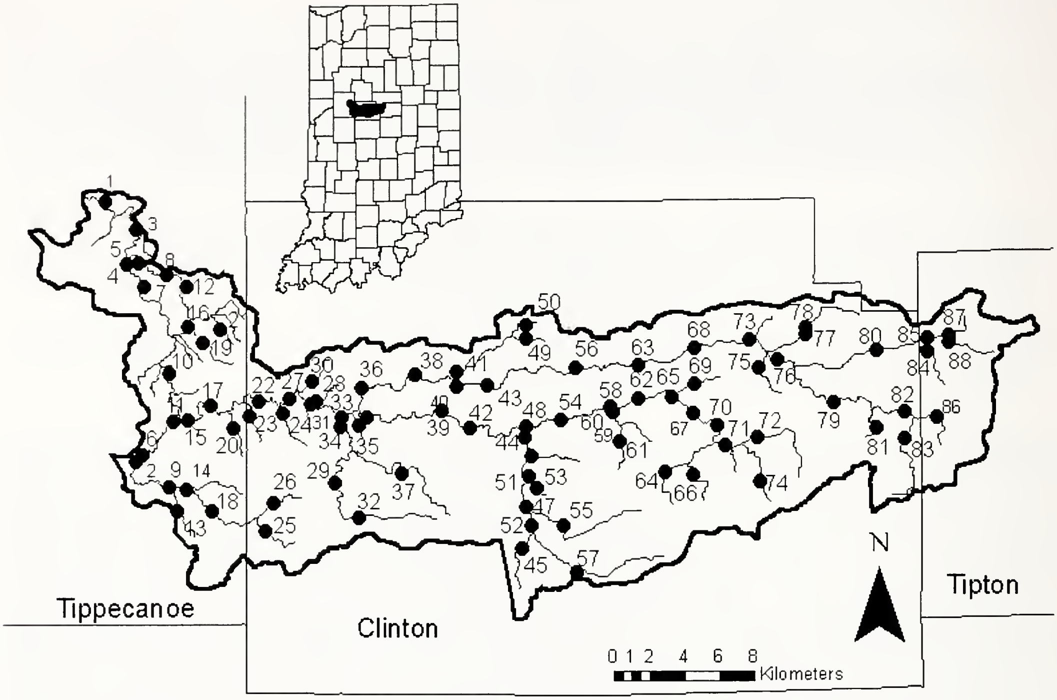

Figure 1.—Distribution of sites in the South Fork Wildcat Creek watershed from 1945 to 2004 (Gerking 1945; Fisher et al. 1998). Numbers refer to site location in Table 1.

from the South Fork Wildcat Creek watershed from 1940 to 2003 (Table 1).

In order to further our knowledge of protected and high quality waterbodies in Indiana, the current study is an intensive survey of the South Fork Wildcat Creek watershed (*n* = 80) (Table 1). This study was conducted by IDEM in August 2004. The objective of this study was to determine the current composition and distribution of fish assemblages inhabiting the waters of the South Fork Wildcat Creek watershed and compare the fish assemblages with that found during past surveys.

METHODS

Study area.—The South Fork Wildcat Creek watershed drains approximately 637 km^2 of southeastern Tippecanoe, central Clinton and northwestern Tipton counties (Fig. 1). The watershed drains from east to west, entering the Wildcat Creek system near West Lafayette. The watershed is located in the Eastern Corn Belt Plain ecoregion (Omernik & Gallant 1988), with agriculture being the primary landuse (80%) (Choi & Engel 2003). The watershed supports a wide range of stream conditions, from portions of the mainstem designated as State Outstanding Resource Waters to agricultural drainage ditches in the headwaters. This wide range of ecological conditions provides diverse habitat settings for fish assemblages.

Study design.—Sampling in the South Fork Wildcat Creek watershed utilized a combination of approaches based on both random and targeted sampling designs. Gerking (1945) targeted locations across the state in order to document, as fully as possible, the distribution of species found. Fisher et al. (1998) targeted sites within the geopolitical boundaries of Tippecanoe County with the intention of documenting the site specific fish assemblage data for future comparisons. From 1995–2003 a random sampling design was used that equally weighted streams in the Wabash River drainage. Sites from 1995 were part of a Regional Environmental Monitoring and Assessment Program (REMAP) for the Eastern Corn Belt Plain designed by the U.S. Environmental Protection Agency (EPA). Sites from 1998–2003 were compiled to provide an assessment of stream water quality for state reporting requirements. Sites for the random sampling designs were selected using Environmental Monitoring and Assessment Program (EMAP) selection methods, which equally weight all stream segments to assess and characterize overall water quality and biotic integrity of the watershed. Sampling included all rivers, streams, canals, and ditches within the Wabash River drainage, including the entire South Fork Wildcat Creek watershed, as indexed in the EPA River Reach File 3. Intensive sampling done in 2004 used a targeted design to evaluate stream water quality and biological condition of the South Fork Wildcat Creek watershed. This targeted approach was spatially intensive, maintaining evenness across the watershed providing a comprehensive inventory of fish assemblages.

Five study periods are summarized, including the baseline study of Gerking (1945) conducted from 1940–1943; collections made by Fisher et al. (1998) in 1994; two probability sampling events, one in 1995 (REMAP) and the second from 1998–2003 (IDEM probability sampling); and the intensive watershed study during 2004. Data reported in this study are based on vouchered fish specimens deposited at the Aquatic Research Center, Indiana Biological Survey, Bloomington, Indiana and at the Museum of Biodiversity, Ohio State University, Columbus, Ohio.

Field collections.—Fish assemblages were assessed from daytime inventories using a variety of equipment. Gerking (1945) primarily used ¼-inch mesh seines of lengths from 8–40 feet (2.5–12 m) and gill nets at selected sites. Collections made post-Gerking (1945) used seines and varying types of electrofishing gear. Small streams (< 3.3 m wetted width) were sampled using seines or a backpack or long-line unit, and wadeable streams (> 3.3 m wetted width) were sampled using a long-line or tote-barge electrofishing unit. Sampling from 1994–2004 was conducted in all representative habitats along a linear reach of stream based on 15 times the wetted width with minimum distances of 50 m and maximum distances of 500 m. All fish encountered were netted and placed into a live-well until completion of the sample zone. Individual fish were identified to species, counted, batch weighed by species, and minimum and maximum length recorded. All individuals were inspected for deformities, eroded fins, lesions, and tumor (DELT) anomalies. Fish were identified using regional identification manuals (Gerking 1955; Smith 1973; Trautman 1981).

Calculations of biological integrity.—The Index of Biotic Integrity (IBI) was used to calculate the results of the fish assemblage data to assess the stream for its ability to support aquatic life (Simon 1992; Simon & Dufour 1998; Simon & Stahl 1998; Simon 2006b). The IBI is composed of 12 metrics that assess the community's species and trophic composition (feeding and reproductive guilds) and fish condition and health. The total IBI score, integrity class and attributes help define fish community characteristics. The Indiana IBI ranks stream quality along a condition gradient with scores ranging from 12 to 60. Scores of 60 represent streams of the highest biological integrity, while scores of 12 represent highly degraded stream systems.

Indiana narrative biological criteria [327 IAC 2-1-3(2)] states that "all waters, except those designated as limited use, will be capable of supporting a well-balanced, warm water aquatic community" (IDEM 2006a). The water quality standard definition of a "well-balanced aquatic community" is "an aquatic community, which is diverse in species composition, contains several different trophic levels, and is not composed mainly of strictly pollution tolerant species" [327 IAC 2-1-9(60)] (IDEM 2006a). A stream segment is non-supporting for aquatic life use when the monitored fish community receives an IBI score of less than 36, which is considered poor or very poor (IDEM 2006b).

RESULTS AND DISCUSSION

Fish assemblages.—Based on a combination of all survey data, 72 species have been collected from the South Fork Wildcat Creek watershed between 1940 and 2004 (Table 2). This number of species represents 36% of the entire fish fauna of Indiana (Simon et al. 2002). The ichthyofauna of the watershed was summarized by Gerking (1945) based on his collections and compiled historical records prior to 1945. No records existed for the South Fork Wildcat Creek watershed prior to 1940, and only three of Gerking's 412 sites were located in the watershed. Gerking (1945) recorded 35 species from these three sites. Fisher et al. (1998) compiled a species list for Tip-

Table 1.—Site locations sampled in the South Fork Wildcat Creek watershed. Site numbers correspond to Table 2 and are shown in Figure 1. Source codes are as follows: a Gerking (1954), b Fisher et al. (1998), c REMAP (1995), d IDEM (1998–2003), e IDEM Stressor ID (2004).

Site No.	Source	County	Locality	Latitude	Longitude
1	b	Tippecanoe	S Fk Wildcat Creek @ CR 100 N	40° 25.56′	−86° 47.18′
2	c	Tippecanoe	Lauramie Creek @ 8 S Rd	40° 17.54′	−86° 46.6′
3	b, e	Tippecanoe	S Fk Wildcat Creek @ SR 26 Near Lafayette	40° 25.5′	−86° 46.5′
4	d, e	Tippecanoe	S Fk Wildcat Creek @ CR 5A E	40° 23.59′	−86° 46.28′
5	e	Tippecanoe	Trib of S Fk Wildcat Creek @ CR 550 E	40° 24.1′	−86° 45.57′
6	e	Tippecanoe	Lauramie Creek @ CR 800 S	40° 18.5′	−86° 45.50′
7	a, b, e	Tippecanoe	S Fk Wildcat Creek @ CR 200 S	40° 23.19′	−86° 45.46′
8	a	Tippecanoe	Unnamed Trib @ CR 7 E	40° 23.41′	−86° 44.49′
9	e	Tippecanoe	Lauramie Creek @ CR 9 S	40° 17.7′	−86° 44.46′
10	b, e	Tippecanoe	S Fk Wildcat Creek @ CR 500 S	40° 20.37′	−86° 44.43′
11	b, e	Tippecanoe	Lauramie Creek @ New Castle Rd	40° 19.8′	−86° 44.34′
12	e	Tippecanoe	Trib of S Fk Wildcat Creek @ CR 200 S	40° 23.19′	−86° 44.3′
13	e	Tippecanoe	Anderson Ditch @ CR 1000 S	40° 16.22′	−86° 44.26′
14	b	Tippecanoe	Lauramie Creek @ U.S. 52	40° 17.3′	−86° 44.2′
15	b, e	Tippecanoe	S Fk Wildcat Creek @ CR 900 E	40° 19.11′	−86° 43.59′
16	e	Tippecanoe	Trib of S Fk Wildcat Creek @ CR 900 E	40° 22.3′	−86° 43.58′
17	e	Tippecanoe	S Fk Wildcat Creek @ 1000 E	40° 19.37′	−86° 43.5′
18	e	Tippecanoe	Lauramie Creek @ CR 1000/10 S	40° 16.22′	−86° 43.3′
29	e	Tippecanoe	Trib of S Fk Wildcat Creek @ CR 1000 E	40° 21.34′	−85° 43.24′
20	e	Tippecanoe	Trib of S Fk Wildcat Creek @ CR 700 S	40° 18.57′	−86° 42.9′
21	e	Tippecanoe	Trib of S Fk Wildcat Creek @ CR 350 S	40° 21.59′	−86° 42.42′
22	e	Clinton	S Fk Wildcat Creek @ CR 950 W	40° 19.45′	−86° 41.8′
23	e	Clinton	Trib of S Fk Wildcat Creek @ CR 250 N	40° 19.18′	−86° 41.31′
24	e	Clinton	Trib of S Fk Wildcat Creek @ CR 250 N	40° 19.23′	−86° 40.9′
25	e	Clinton	McClellan Fickle Ditch @ CR 180 S	40° 15.44′	−86° 40.54′
26	e	Clinton	Lauramie Creek @ CR 900 W	40° 16.38′	−86° 40.32′
27	e	Clinton	S Fk Wildcat Creek @ CR 850 W	40° 19.50′	−86° 39.55′
28	a, e	Clinton	S Fk Wildcat Creek @ Mulberry Jefferson Rd	40° 19.40′	−86° 39.3′
29	e	Clinton	Lick Run @ Newcastle Road	40° 17.13′	−86° 38.6′
30	e	Clinton	Trib of S Fk Wildcat Creek @ Gasline Rd	40° 20.20′	−86° 38.59′
31	d	Clinton	S Fk Wildcat Creek @ W Mulberry-Jefferson Rd	40° 19.45′	−86° 38.50′
32	e	Clinton	Lick Run @ CR 600 W	40° 16.10′	−86° 37.8′
33	e	Clinton	Trib of S Fk Wildcat Creek @ CR 600 W	40° 19.0′	−86° 37.6′
34	e	Clinton	Spring Creek @ CR 200 N	40° 18.58′	−86° 37.50′
35	e	Clinton	S Fk Wildcat Creek @ CR 580 W	40° 19.14′	−86° 37.48′
36	e	Clinton	Kilmore Creek @ CR 600 W Near Hamilton	40° 20.9′	−86° 37.0′
37	c, e	Clinton	Heavilon Ditch @ CR 450 W	40° 17.31′	−86° 35.24′
38	e	Clinton	Kilmore Creek @ CR 400 W	40° 20.32′	−86° 34.50′
39	e	Clinton	S Fk Wildcat Creek @ CR 300 W	40° 19.26′	−86° 33.45′
40	a	Clinton	Kilmore Creek @ 2 mi. S Cambria	40° 20.10′	−86° 33.11′
41	e	Clinton	Boyles Ditch @ CR 400 N	40° 20.37′	−86° 33.11′
42	c, e	Clinton	S Fk Wildcat Creek @ CR 200 N	40° 18.54′	−86° 32.37′
43	e	Clinton	Kilmore Creek @ CR 130 W	40° 20.12′	−86° 31.55′
44	e	Clinton	Unnamed Trib @ CR 100 N	40° 18.2′	−86° 30.9′
45	e	Clinton	Trib of Prairie Creek @ SR 38/39	40° 15.10′	−86° 30.35′
46	e	Clinton	Prairie Creek @ CR 150 N	40° 18.36′	−86° 30.26′
47	e	Clinton	Prairie Creek @ Clay St	40° 16.27′	−86° 30.25′
48	e	Clinton	S Fk Wildcat Creek @ CR 00 Rd	40° 18.55′	−86° 30.22′
49	e	Clinton	Trib of Boyles Ditch @ CR 00 Rd	40° 21.39′	−86° 30.21′
50	e	Clinton	Unnamed Trib @ CR 00 Rd	40° 22.4′	−86° 30.21′

Table 1.—Continued.

Site No.	Source	County	Locality	Latitude	Longitude
51	e	Clinton	Prairie Creek @ Kyger St	40° 17.24′	−86° 30.18′
52	e	Clinton	Prairie Creek @ Kelley Rd	40° 15.52′	−86° 30.10′
53	e	Clinton	Trib of Prairie Creek @ Washington Ave	40° 17.3′	−86° 29.57′
54	e	Clinton	S Fk Wildcat Creek @ CR 130 E	40° 19.8′	−86° 28.57′
55	e	Clinton	Mann Ditch @ CR 150 S	40° 15.52′	−86° 28.53′
56	e	Clinton	Kilmore Creek @ CR 180 E	40° 20.43′	−86° 28.23′
57	e	Clinton	Prairie Creek @ CR 180 E	40° 14.27′	−86° 28.21′
58	e	Clinton	S Fk Wildcat Creek @ CR 300 E	40° 19.31′	−86° 26.60′
59	d	Clinton	Unnamed Trib @ CR 250 N	40° 19.25′	−86° 26.55′
60	e	Clinton	Trib of S Fk Wildcat Creek @ CR 250 N	40° 19.21′	−86° 26.52′
61	e	Clinton	Trib of S Fk Wildcat Creek @ Michigantown Rd	40° 18.28′	−86° 26.37′
62	e	Clinton	S Fk Wildcat Creek @ CR 400 E	40° 19.46′	−86° 25.51′
63	e	Clinton	Kilmore Creek @ CR 400 E	40° 20.47′	−86° 25.51′
64	e	Clinton	Talbert Ditch @ CR 500 E	40° 17.30′	−86° 24.48′
65	e	Clinton	S Fk Wildcat Creek @ CR 300 N	40° 19.48′	−86° 24.31′
66	e	Clinton	Walker Ditch @ SR 29	40° 17.24′	−86° 23.40′
67	c	Clinton	S Fk Wildcat Creek @ Michigantown Rd	40° 19.19′	−86° 23.39′
68	e	Clinton	Kilmore Creek @ SR 29	40° 21.20′	−86° 23.35′
69	e	Clinton	Jenkins Ditch @ SR 29	40° 20.12′	−86° 23.35′
70	e	Clinton	S Fk Wildcat Creek @ CR 200 N	40° 18.57′	−86° 22.39′
71	c, e	Clinton	S Fk Wildcat Creek @ CR 730 E	40° 18.19′	−86° 22.22′
72	e	Clinton	S Fk Wildcat Creek @ CR 830 E	40° 18.33′	−86° 21.5′
73	d, e	Clinton	Kilmore Creek @ CR 500 N	40° 21.34′	−86° 21.22′
74	e	Clinton	Cripe Ditch @ Western Walker Rd	40° 17.13′	−86° 20.60′
75	e	Clinton	Davis Ditch @ CR 400 N	40° 20.41′	−86° 20.60′
76	e	Clinton	Kilmore Creek @ CR 900 E	40° 20.55′	−86° 20.15′
77	e	Clinton	Kilmore Creek @ CR 1000 E	40° 21.44′	−86° 19.7′
78	e	Clinton	Stump Creek @ CR 1000 E	40° 21.56′	−86° 19.7′
79	c, e	Clinton	Swamp Creek @ CR 1100 E	40° 19.36′	−86° 17.58′
80	e	Clinton	Kilmore Creek @ CR 750 W	40° 21.12′	−86° 16.16′
81	e	Clinton	Trib of Swamp Creek @ CR 1250 E	40° 18.50′	−86° 16.16′
82	e	Clinton	Swamp Creek @ CR 1350 E	40° 19.18′	−86° 15.8′
83	e	Clinton	Paris Ditch @ CR 1350 E	40° 18.27′	−86° 15.8′
84	e	Tipton	Lydy Fillenworth Ditch @ CR 600 W	40° 21.9′	−86° 14.11′
85	e	Tipton	Shanty Creek @ CR 600 W	40° 21.32′	−86° 14.44′
86	e	Tipton	Mott Ditch@ CR 600 W	40° 19.7′	−86° 13.52′
87	e	Tipton	Shanty Creek @ CR 500 W	40° 21.25′	−86° 13.19′
88	e	Tipton	Collier Ditch @ CR 1100 W	40° 21.39′	−86° 13.19′

pecanoe County that incorporated data from seven sites in the South Fork Wildcat Creek watershed. Collections made between June and December 1994 recorded 47 species. In 1995, REMAP recorded 38 species from six sites. Forty-four species were recorded from five locations in the watershed through IDEM sampling efforts between 1998 and 2003. In 2004, IDEM conducted the most intensive survey of the South Fork Wildcat Creek watershed and collected 65 species from 80 sites.

Combination of records from sampling periods from 1995–2004 show that the dominant species by number included creek chub (*Semotilus atromaculatus*) (19%), central stoneroller (*Campostoma anomalum*) (14%), and bluntnose minnow (*Pimephales notatus*) (9%) (Table 3).

Fish assemblages during 1942–1945.—Gerking (1945) documented 35 species from three sites in the South Fork Wildcat Creek watershed (Table 2). Sampling sites were not chosen to represent the highest quality streams in the watershed, but were representative of the prevailing conditions at the time. Gerking (1945) reported common shiner (*Luxilus cor-*

Table 2.—List of fish species collected from the South Fork Wildcat Creek watershed. Numbers indicate the sites at which each species has been collected based on information in Table 1 and Figure 1.* This species was identified as *Lucxilus cornutus chrysocephalus*, and is now recognized as a valid species, *Luxilus chrysocephalus.*

Species	Gerking (1945)	Fisher et al., (1994)	REMAP (1995)	IDEM (1998–2003)	IDEM Stressor ID (2004)
Petromyzontidae					
Ichthyomyzon unicuspis		3, 10			
Lepisosteidae					
Lepisosteus osseus		10			
Clupidae					
Dorosoma cepedianum		3, 7	7, 37	73	3, 7, 10, 22, 27, 28, 39, 56, 63, 68, 76
Cyprinidae					
Campostoma anomalum	7, 28	1, 3, 7, 10, 11, 14, 15	2, 37, 42, 67, 71, 79	4, 31, 59, 73	3–6, 9–11, 16, 17, 20, 22–24, 28–30, 32–34, 36–39, 41–44, 48, 51–58, 60–62, 65, 68–73, 75, 80
Campostoma oligolepis					13, 18, 26, 35, 45–47, 76–79, 85
Cyprinella spiloptera	7, 28	1, 3, 7, 10, 11, 15	37, 67, 79	4, 31, 73	3, 4, 7, 9, 10, 15, 17, 22, 27, 28, 33–36, 39, 42, 43, 46, 48, 54, 56, 58, 62, 63, 65, 68, 73, 76, 79, 80, 85, 87
Cyprinella whipplei		1, 3, 7		73	3, 10, 35
Cyprinus carpio		3, 7, 10	2, 79	31, 73	3, 9, 10, 15, 22, 26, 35, 39, 45, 47, 48, 56, 58, 63, 68, 73, 76
Ericymba buccata	7, 28, 40	1, 3 ,10, 11, 14	2, 37, 67, 71	4, 8, 73	4, 1, 16, 18, 33–36, 38, 39, 43, 46, 48, 52, 54–57, 62, 70, 73, 76
Hybognathus nuchalis	7			4	4
Hybopsis amblops	7, 28	1, 3, 7, 10, 11	2, 37	4, 31, 73	3, 4, 6, 22, 28, 33–36, 39, 42, 43, 46, 48, 54, 56, 63, 68, 73
Luxilus chrysocephalus		3, 7, 10, 11, 12, 15	2, 37, 42, 67, 71, 79		6, 9, 18, 34, 42, 46–48, 51, 52, 55, 58, 62, 68, 79
*Luxilus cornutus**	7, 28, 40				

Table 2.—Continued.

Species	Gerking (1945)	Fisher et al., (1994)	REMAP (1995)	IDEM (1998–2003)	IDEM Stressor ID (2004)
Lythrurus umbratilis	7, 28	3, 10, 11, 12, 15	67, 79	59, 73	4, 26, 32, 39, 42, 46, 48, 52, 54, 56, 68, 73, 80, 81, 87
Nocomis biguttatus					37
Nocomis micropogon	7	1, 3, 7, 10, 11, 15	2	4, 31	4, 10, 33, 35
Notemigonus crysoleucus					26, 32, 37
Notropis rubellus	7, 28	7, 10, 11		31	10, 11, 28, 33–36, 43
Notropis stramineus	7	1, 3, 7, 10, 11, 15	2, 37, 67, 71	4, 31, 73	3, 4, 6, 9, 33, 35, 36, 38, 39, 42, 43, 46, 48, 51, 54, 56, 58, 62, 65, 68, 73, 76, 80
Notropis volucellus	7, 28	1			
Notropis wickliffi		1			
Phenacobius mirabilis	7	1, 3			35
Phoxinus erythrogaster					4, 13, 16, 19, 20, 23, 24, 30, 45, 57
Pimephales notatus	7, 28, 40	1, 3, 7, 10, 11, 14, 15	2, 37, 42, 67, 71, 79	4, 8, 31, 59, 73	3, 4, 6, 9, 10, 13, 15–18, 22, 23, 26–30, 32–34, 36–39, 42–48, 51, 52, 54–58, 60–65, 68, 70–76, 79, 80, 83–85, 87
Pimephales promelas		15			33, 43, 57
Rhinichthys obtusus		3, 11, 14		8, 59	4, 6, 9, 13, 16, 18–20, 23, 24, 29, 30, 32–35, 37, 41, 42, 45, 46, 51–55, 57, 58, 60–62, 64, 65, 69–72, 75, 81, 82
Semotilus atromaculatus	7	3, 10, 11, 14	2, 37, 42, 67, 71, 79	8, 59, 73	4–6, 9, 11–13, 16, 18–20, 23–26, 29, 30, 32–39, 41–58, 60–65, 68–81, 83–85, 87
Esocidae					
Esox americanus	28			8	3, 5, 12, 22, 36, 38, 43, 56, 81–83, 85

Table 2.—Continued.

Species	Gerking (1945)	Fisher et al., (1994)	REMAP (1995)	IDEM (1998–2003)	IDEM Stressor ID (2004)
Catostomidae					
Carpiodes carpio					7, 39
Carpiodes cyprinus			79	73	7, 10, 15, 22, 27, 28
Carpiodes velifer					10, 15, 17
Catostomus commersonii	28	7, 11, 14, 15	2, 37, 67, 71, 79	59, 73	4, 6, 9–11, 13, 16–18, 20, 22–24, 26, 29, 32–39, 42, 43, 46–48, 51–58, 60–63, 65, 68–76, 79–81, 83
Erimyzon oblongus	40		79	73	30, 62, 63, 68, 70, 72, 77, 79–84, 87
Hypentelium nigricans	7	1, 3, 7, 10, 11, 14, 15	2, 37, 42, 67, 71, 79	4, 31, 73	3–7, 9–11, 15, 17, 22, 27, 28, 33–36, 38, 39, 42, 43, 46, 48, 51, 54, 56, 58, 62, 63, 65, 68, 70, 73, 76
Minytrema melanops			67	73	15, 35, 39, 46, 48, 54, 56, 58, 62, 63, 65, 68, 73, 79, 80, 85
Moxostoma anisurum	7	3, 10, 15		4	3, 4, 7, 15, 17, 22, 27, 35, 39
Moxostoma duquesnei		1, 3, 7, 10, 15	37	4, 31, 73	3, 4, 7, 10, 15, 17, 22, 27, 28, 33, 35, 36, 38, 39, 42, 43, 48, 56, 58, 63, 68, 76, 79
Moxostoma erythrurum	7, 28	3, 15	37, 67	4, 31, 73	3, 4, 7, 9, 10, 15, 17, 22, 27, 28, 33, 35, 36, 38, 39, 43, 48, 54, 56, 58, 63, 65, 68, 73, 76
Moxostoma macrolepidotum		1, 7		31	1, 7, 15, 28
Ictaluridae					
Ameiurus melas		3	79		26, 57, 81, 83, 85
Ameiurus natalis		3, 11, 14	42, 67, 79	73	9, 10, 26, 37, 38, 43, 44, 46–48, 51, 52, 56, 62–65, 68, 70, 72, 73, 76, 77, 79, 80, 83, 85–87

Table 2.—Continued.

Species	Gerking (1945)	Fisher et al., (1994)	REMAP (1995)	IDEM (1998–2003)	IDEM Stressor ID (2004)
Ameiurus nebulosus			2, 42		56, 65
Ictalurus punctatus					3, 7, 35
Noturus flavus	7	3	37		39, 43
Noturus gyrinus					80, 85
Noturus miurus	7	10		4	4, 10, 43, 56
Pylodictis olivaris		1			
Fundulidae					
Fundulus notatus			79	73	64, 70, 76–78, 80, 82, 84, 85
Poeciliidae					
Gambusia affinis					64
Centrarchidae					
Ambloplites rupestris	7, 28	3, 7, 10, 11	2, 37, 67	4, 31	4, 7, 9–11, 15, 17, 18, 22, 27, 28, 33, 35, 36, 38, 42, 43, 46–48, 51, 52, 54, 56, 58, 62, 65, 71, 72, 79
Lepomis cyanellus	28	1, 3, 7, 10, 11	37, 42, 67, 71, 79	8, 59, 73	3, 4, 9–12, 17, 18, 24, 26–29, 32, 34–39, 43–49, 51, 53, 55–57, 61–63, 65, 68, 70–73, 75–88
Lepomis gulosus					27
Lepomis humilis				31, 73	22, 28, 73, 79, 83
Lepomis macrochirus	28	3, 7, 10	37, 79	4, 73	3, 4, 7, 9, 10, 15, 22, 23, 27, 28, 33–39, 42, 48, 54, 55, 62, 63, 68, 70, 73, 76–80, 85, 87
Lepomis megalotis	28, 40	1, 3, 7, 10, 11, 14, 15	2, 37, 42, 67, 71, 79	4, 31, 73	3, 4, 6, 7, 9, 10, 12, 15, 17, 22, 27, 28, 33–36, 38, 39, 42, 43, 46–48, 51, 52, 54, 56–58, 62, 63, 65, 68, 70, 72, 73, 76–80, 85, 87
Lepomis microlophus		3			
Micropterus dolomieu	7, 28	1, 3, 7, 10, 11, 15	2, 37, 67	4, 31	3, 4, 6, 7, 9–11, 15, 17, 22, 23, 27, 28, 33–36, 38, 39, 42, 43, 46, 48, 54, 56, 58, 62, 65, 70

Table 2.—Continued.

Species	Gerking (1945)	Fisher et al., (1994)	REMAP (1995)	IDEM (1998–2003)	IDEM Stressor ID (2004)
Micropturus punctulatus	7	1, 3, 10		73	4, 10, 18, 26, 28, 33, 34, 39, 44, 48, 55, 58, 61, 63, 65, 68, 73, 75–79, 85
Micropturus salmoides	40			73	3, 42, 47, 48, 58, 62, 65, 68, 70, 73, 80, 83, 85
Pomoxis annularis		3		73	3, 68
Pomoxis nigromaculatus					35
Percidae					
Etheostoma blennioides	7, 40	1, 3, 7, 10, 11, 15	2, 37, 42, 67, 71, 79	4, 31, 73	3, 4, 6, 7, 9–11, 15, 17, 18, 22, 27, 28, 33–36, 38, 39, 42, 43, 46, 48, 51, 54, 56, 58, 62, 63, 65, 68, 70, 72, 73, 76, 80, 87
Etheostoma caeruleum	7, 28, 40	1, 3, 7, 10, 11, 15	37, 42, 67, 71, 79	4, 31, 73	3, 4, 6, 7, 9–11, 15, 17, 22, 23, 27–29, 33–36, 38, 39, 42, 43, 47, 48, 51, 52, 54, 56, 58, 62, 63, 65, 68, 70, 71, 73, 76, 78
Etheostoma camurum	7				
Etheostoma flabellare	7	11, 14	37		28, 36, 43
Etheostoma microperca			71		12, 62, 64, 71, 72, 74
Etheostoma nigrum	28, 40	3, 10, 11, 14	2, 37, 42, 67, 71, 79	4, 59, 73	3, 4, 6, 7, 9–11, 15, 18, 22–29, 32–39, 42–48, 51, 52, 54–58, 60, 62–65, 68–73, 75, 76, 79, 80, 87
Etheostoma spectabile		3, 10, 11, 14	2, 42, 67, 71, 79	8	3–6, 9–11, 13, 16–20, 23–26, 29, 30, 32, 35, 37, 42, 44–49, 51, 52, 54, 55, 58, 61–64, 69–72, 75, 77, 78, 80, 81, 87
Percina caprodes			37		28
Percina maculata				73	27, 43, 56, 63, 68, 73
Percina sciera		1, 3, 10, 11	2, 37	4	3, 4, 10, 11, 15, 17, 22, 28, 33, 38, 43, 63

Table 2.—Continued.

Species	Gerking (1945)	Fisher et al., (1994)	REMAP (1995)	IDEM (1998–2003)	IDEM Stressor ID (2004)
Sciaenidae					
Aplodinotus grunniens					3, 7, 10, 33, 35, 63
Cottidae					
Cottus bairdii	7	3, 10, 11, 14	2, 37	4	4, 6, 9, 11, 13, 16, 18, 23, 24, 29, 32, 34, 36–38, 41–43

nutus chrysocephalus) from the watershed. The taxonomy of the *Luxilus* group post-Gerking has changed, and it is clear that the species reported by Gerking is actually the striped shiner (*Luxilus chrysocephalus*). Although these two species occur in the Great Lakes basin, only *Luxilus chrysocephalus* is present in the Ohio River basin. Gerking (1945) was the last to report the bluebreast darter (*Etheostoma camurum*) from the South Fork Wildcat Creek watershed. This species, which was recently removed from the state endangered species list, is believed to be extirpated from the watershed. No further record of the species is known from the South Fork Wildcat Creek watershed; however, the species has been collected from the Wabash River near the mouth of Wildcat Creek (B.E. Fisher, Indiana DNR, pers. comm.).

Fish assemblages during 1994.—Fisher et al. (1998) collected 47 species, which included most of the species previously collected by Gerking (Table 2) and added 18 new records for the South Fork Wildcat Creek watershed, including silver lamprey (*Ichthyomyzon unicuspis*), longnose gar (*Lepisosteus osseus*), gizzard shad (*Dorsoma cepedianum*), steelcolor shiner (*Cyprinella whipplei*), carp (*Cyprinus carpio*), channel shiner (*Notropis wickliffi*), fathead minnow (*Pimephales promelas*), western blacknose dace (*Rhinichthys obtusus*), river carpsucker (*Carpiodes carpio*), black redhorse (*Moxostoma duquesnei*), shorthead redhorse (*Moxostoma macrolepidotum*), black bullhead (*Ameiurus melas*), yellow bullhead (*Ameiurus natalis*), flathead catfish (*Pylodictis olivaris*), redear sunfish (*Lepomis microlophus*), white crappie (*Pomoxis annularis*), orangethroat darter (*Etheostoma spectabile*), and dusky darter (*Percina sciera*) (Table 2). Fisher et al. documented the last records for six species (*Ichthyomyzon unicuspis*, *Lepisosteus osseus*, *Notropis volucellus*, *Notropis wickliffi*, *Pylodictis olivaris*, and *Lepomis microlophus*) from the South Fork Wildcat Creek Watershed. All of the species last collected by Fisher et al. are large-river habitat species that may have entered the South Fork Wildcat Creek from the mainstem Wabash River. Fisher's sites were less than 14 river miles (22.5 km) from the mouth of the Wabash River.

Fish assemblages during 1994–1995.—During this period, 38 species were collected during a survey of the Eastern Corn Belt Plain (Table 2; Simon unpubl. data). Six species were newly recorded from the watershed including: quillback (*Carpiodes cyprinus*), spotted sucker (*Minytrema melanops*), brown bullhead (*Ameiurus nebulosus*), blackstripe topminnow (*Fundulus notatus*), least darter (*Etheostoma microperca*), and logperch (*Percina caprodes*) (Table 2). All of the sucker species records are large-river habitat species. These species are more difficult to collect and are not generally present in small streams. The least darter (Etheostoma microperca) is one of the smallest fish in North America and is often overlooked and easily missed due to gear problems. By using the smallest standard bar-mesh (5 mm stretch), the capture of the least darter was recorded. The logperch is a large-to moderate-sized river species that occurs in run habitat types.

Fish assemblages during 1998–2003.—During this period 44 species were collected from five sites in the South Fork Wildcat Creek watershed (Table 2). Two species were newly recorded during this time period, including orangespotted sunfish (*Lepomis humilis*) and blackside darter (*Percina maculata*)

Table 3.—Comparison of probabilistic data collected from three periods in the South Fork Wildcat Creek watershed from 1995 to 2004. REMAP - Regional Environmental Monitoring and Assessment Program (1995); Probability - Random sampling design on Upper Wabash River drainage (1995–2003); Stressor - Targeted sampling design on South Fork Wildcat Creek drainage (2004).

	REMAP		Probability		Stressor		Total	
Species	Count	%	Count	%	Count	%	Count	%
Clupeidae								
Dorosoma cepedianum	1	<1%	12	1%	90	<1%	103	<1%
Cyprinidae								
Campostoma anomalum	417	22%	56	3%	3399	15%	3872	14%
Campostoma oligolepis					549	2%	549	2%
Cyprinella spiloptera	18	1%	65	4%	367	2%	450	2%
Cyprinella whipplei		<1%	1	<1%	9	<1%	10	<1%
Cyprinus carpio	16	1%	17	1%	67	<1%	100	<1%
Ericymba buccata	18	1%	36	2%	173	1%	227	1%
Hybognathus nuchalis			1	<1%			1	<1%
Hybopsis amblops	8	<1%	30	2%	337	1%	375	1%
Luxilus chrysocephalus	69	4%			92	<1%	161	1%
Lythrurus umbratilis	3	<1%	12	1%	79	<1%	94	<1%
Nocomis biguttatus					1	<1%	1	<1%
Nocomis micropogon	6	<1%	12	1%	4	<1%	22	<1%
Notemigonus crysoleucus					12	<1%	12	<1%
Notropis rubellus			14	1%	50	<1%	64	<1%
Notropis stramineus	39	2%	39	2%	255	1%	333	1%
Phenacobius mirabilis					1	<1%	1	<1%
Phoxinus erythrogaster					137	1%	137	1%
Pimephales notatus	205	11%	390	22%	1996	9%	2591	10%
Pimephales promelas	2				3	<1%	5	<1%
Rhinichthys obtusus			7	<1%	1742	7%	1749	7%
Semotilus atromaculatus	224	12%	220	13%	4773	21%	5217	19%
Esocidae								
Esox americanus			3	<1%	44	<1%	47	<1%
Catostomidae								
Carpiodes carpio	1	<1%		<1%	9	<1%	10	<1%
Carpiodes cyprinus	2	<1%	1	<1%	10	<1%	13	<1%
Carpiodes velifer					6	<1%	6	<1%
Catostomus commersonii	126	7%	44	3%	1205	5%	1375	5%
Erimyzon oblongus	12	1%	6	<1%	39	<1%	57	<1%
Hypentelium nigricans	63	3%	36	2%	440	2%	539	2%
Minytrema melaonps	1	<1%	27	2%	60	<1%	88	<1%
Moxostoma anisurum			1	<1%	20	<1%	21	<1%
Moxostoma duquesnei	8	<1%	75	4%	333	1%	416	2%
Moxostoma erythrurum	6	<1%	97	6%	319	1%	422	2%
Moxostoma macrolepidotum			1	<1%	5	<1%	6	<1%
Ictaluridae								
Ameiurus melas	2	<1%			11	<1%	13	<1%
Ameiurus natalis	10	1%	45	3%	107	<1%	162	1%
Ameiurus nebulosus	2	<1%			2	<1%	4	<1%
Ictalurus punctatus					4	<1%	4	<1%
Noturus flavus	1	<1%			2	<1%	3	<1%
Noturus gyrinus					3	<1%	3	<1%
Noturus miurus			1	<1%	8	<1%	9	<1%

Table 3.—Continued.

Species	REMAP		Probability		Stressor		Total	
	Count	%	Count	%	Count	%	Count	%
Fundulidae								
Fundulus notatus	14	1%	4	<1%	47	<1%	65	<1%
Poeciliidae								
Gambusia affinis					6	<1%	6	<1%
Centrarchidae								
Ambloplites rupestris	9	<1%	4	<1%	153	1%	166	1%
Lepomis cyanellus	22	1%	92	5%	742	3%	856	3%
Lepomis gulosus					2	<1%	2	<1%
Lepomis humilis			16	1%	22	<1%	38	<1%
Lepomis macrochirus	3	<1%	22	1%	150	1%	175	1%
Lepomis megalotis	63	3%	192	11%	781	3%	1036	4%
Micropterus dolomieu	5	<1%	3	<1%	164	1%	172	1%
Micropturus punctulatus			17	1%	55	<1%	72	<1%
Micropturus salmoides			4	<1%	34	<1%	38	<1%
Pomoxis annularis			1	<1%	2	<1%	3	<1%
Poxomis nigromaculatus					1	<1%	1	<1%
Percidae								
Etheostoma blennioides	119	6%	59	3%	1007	4%	1185	4%
Etheostoma caeruleum	152	8%	23	1%	836	4%	1011	4%
Etheostoma flabellare	8	<1%			5	<1%	13	<1%
Etheostoma microperca	1	<1%			108	<1%	109	<1%
Etheostoma nigrum	113	6%	29	2%	1150	5%	1292	5%
Etheostoma spectabile	128	7%	1	<1%	724	3%	853	3%
Percina caprodes	1	<1%			1	<1%	2	<1%
Percina maculata			1	<1%	13	<1%	14	<1%
Percina sciera	3	<1%	24	1%	44	<1%	71	<1%
Sciaenidae								
Aplodinotus grunniens					11	<1%	11	<1%
Cottidae								
Cottus bairdii	8	<1%	6	<1%	408	2%	422	2%

(Table 2). *Percina maculata* prefers woody debris habitats, while *Lepomis humilis* is characteristic of open, turbid, prairie streams. Those species collected during these sampling events that were not previously recorded in 1994 sampling events include: Mississippi silvery minnow (*Hybognathus nuchalis*), grass pickerel (*Esox americanus*), orangespotted sunfish (*Lepomis humilis*), largemouth bass (*Micropturus salmoides*), and blackside darter (*Percina maculata*) (Table 2).

Fish assemblages during 2004.—During this time period 65 species were collected from 80 sites (Table 2). Eleven species were newly collected during this period including: largescale stoneroller (*Campostoma oligolepis*), hornyhead chub (*Nocomis biguttatus*), golden shiner (*Notemigonus crysoleucus*), southern redbelly dace (*Phoxinus erythrogaster*), river carpsucker (*Carpiodes carpio*), highfin carpsucker (*Carpiodes velifer*), channel catfish (*Ictalurus punctatus*), tadpole madtom (*Noturus gyrinus*), mosquitofish (*Gambusia affinis*), warmouth (*Lepomis gulosus*), black crappie (*Poxomis nigromaculatus*), and freshwater drum (*Aplodinotus grunniens*) (Table 2).

Fish fauna similarity concordance.—During 2004, we re-sampled four of the seven sites sampled by Fisher et. al. (1998) from 1994. These four sites were located in Tippecanoe County. The South Fork Wildcat Creek, SR 26 near Lafayette, had 43 species recorded during 1994 and 2004 with a simi-

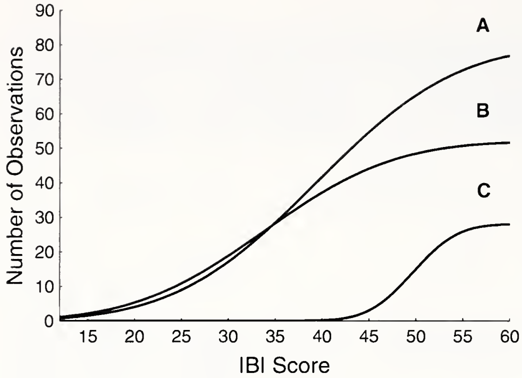

Figure 2.—Cumulative frequency distribution of IBI scores for the South Fork Wildcat Creek watershed for the 2004 survey. A = all sites, B = headwater sites (drainage area < 51.8 km^2), and C = wadeable/mainstem sites (drainage area > 51.8 km^2).

larity coefficient of 51.2%. The site on South Fork Wildcat Creek, CR 200 S bridge, yielded 42 species with a similarity coefficient of 26.2%, while a third site on South Fork Wildcat Creek yielded 37 species with similarity of 54.1%. The last site, Lauramie Creek, New Castle Road, had 26 species with a similarity coefficient of 53.8%.

Condition of the South Fork Wildcat Creek watershed.—Based on the 2004 intensive watershed survey, the South Fork Wildcat Creek watershed had an index of biotic integrity scores that range from 12 to 56 (mean = 39; Fig. 2). Seventy percent of the watershed is exceeding the State minimum IBI score with 29% achieving IBI scores ≥48, which is considered to be "good" to "excellent" condition. Thirty percent of the watershed is considered to be biologically impaired (IBI score <36). All sites demonstrating biological impairments (IBI ≤35) were headwater streams with drainage areas less then 51.8 km^2 (Fig. 2). IBI scores for these headwater streams range from 12 to 56 (mean = 34). Conversely, IBI scores for those streams with drainage areas greater then 51.8 km^2 range from 42 to 54 (mean=50; Fig. 2). Restoration efforts should focus on headwater streams in the watershed in order to protect the biological integrity of the larger streams in the watershed.

The current comprehensive study of the fishes of the South Fork Wildcat Creek watershed advances our understanding of this rich and diverse watershed increasing the known species from the watershed to 73. The need for comprehensive inventories of watershed-specific fish assemblages is vital for trend assessment and to determine changes to specific guild or sensitive species. With continued emphasis being placed on maintaining and improving the water quality and biological integrity of watersheds, further efforts should be made to restore headwater streams in the South Fork Wildcat Creek watershed.

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LITERATURE CITED

Carney, D.A., L.M. Page & T.M. Keevin. 1998. Fishes of the Tippecanoe River, Indiana: An outstanding midwestern stream. Proceedings of the Indiana Academy of Science 101:201–209.

Choi, J. & B.A. Engel. 2003. Watershed delineation: Web-GIS tools for spatial hydrologic analysis. Available at: http://pasture.ecn.purdue.edu/&sim;jychoi/wd_home/. Accessed 13 July 2006.

Fisher, B.E., W.P. Wente, T.P. Simon & A. Spacie. 1998. The fishes of Tippecanoe County, Indiana. Proceedings of the Indiana Academy of Science 107:151–166.

Gerking, S.D. 1945. Distribution of Indiana fishes. Investigations of Indiana Lakes and Streams 3: 1–137.

Gerking, S.D. 1955. Key to the fishes of Indiana. Investigations of Indiana Lakes and Streams 4: 49–86.

IDEM (Indiana Department of Environmental Management). 2006a. Title 327 of the Indiana Administrative Code, Indiana Environmental Rules: Water, Indiana Department of Environmental Management, Indianapolis, Indiana. http://in.gov/legislative/iac/iac_title?iact=327

IDEM (Indiana Department of Environmental Management). 2006b. Indiana Integrated Water Monitoring and Assessment Report 2006. B-001-OWQ-A-00-06-R3. (Jody Arthur, ed.). Office of Water Quality, Indiana Department of Environmental Management, Indianapolis, Indiana. http://www.in.gov/idem/programs/water/305b/index.html

IDEM (Indiana Department of Environmental Management). 1998. Surface Water Quality Monitoring Strategy 1996–2000. IDEM/32/01/013/1998. Indianapolis, Indiana.

IDEM (Indiana Department of Environmental Management). 2001. Surface Water Quality Monitoring Strategy 2001–2005. IDEM/32/01/021/2001. Indianapolis, Indiana.

Omernik, J.M. & A.L. Gallant. 1988. Ecoregions of the upper midwest states. EPA/600/3-88/037. U.S. Environmental Protection Agency, Corvallis, Oregon.

Simon, T.P. 1992. Biological Criteria Development for Large Rivers with an Emphasis on an Assessment of the White River Drainage, Indiana. EPA 905/R-92/006. U.S. Environmental Protection Agency, Chicago, Illinois.

Simon, T.P. 2006a. Biodiversity of fishes in the Wabash River: Status, indicators, and threats. Proceedings of the Indiana Academy of Science 115:000–000.

Simon, T.P. 2006b. Development, calibration, and validation of an Index of Biotic Integrity for the Wabash River. Proceedings of the Indiana Academy of Science 115:000–000.

Simon, T.P. & R.L. Dufour. 1998. Development of Index of Biotic Integrity Expectations for the Ecoregions of Indiana. V. Eastern Corn Belt Plain. EPA 905/R-96/003. U.S. Environmental Protection Agency, Chicago, Illinois.

Simon, T.P. & J.R. Stahl. 1998. Development of Index of Biotic Integrity Expectations for the Wabash River. EPA 905/R-96/005. U.S. Environmental Protection Agency, Chicago, Illinois.

Simon, T.P., J.O. Whitaker, Jr., J.S. Castrale & S.A. Minton. 2002. Revised checklist of the vertebrates of Indiana. Proceedings of the Indiana Academy of Science 111:182–214.

Simon, T.P., R.L. Dufour & B.E. Fisher. 2005. Changes in the biological integrity of fish communities in the Patoka River drainage as a result of anthropogenic disturbance from 1888 to 2001. *In* Historical Changes in Large River Fish Assemblages of the Americas. (J.N. Rinne, R.M. Hughes & B. Calamusso, eds.). American Fisheries Society Symposium 45.

Smith, P.W. 1973. The Fishes of Illinois. University of Illinois Press. Champaign, Illinois.

Trautman, M.B. 1981. The Fishes of Ohio. Ohio State University Press. Columbus, Ohio.

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BIODIVERSITY OF FISHES IN THE WABASH RIVER: STATUS, INDICATORS, AND THREATS

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ABSTRACT. Anthropogenic impacts on native Wabash River fish species have caused extinctions, fragmentation and loss of habitat, and range reductions that have imperiled species. Seven species that have been extirpated include the alligator gar (*Atractosteus spatula*), harelip sucker (*Moxostoma lacerum*), crystal darter (*Crystallaria asprella*), saddleback darter (*Percina vigil*), channel darter (*Percina copelandi*), stargazing darter (*Percina uranidea*), and popeye shiner (*Notropis ariommus*). The harelip sucker occurred in the Tippecanoe River but became extinct during the early 1900s. Banded pygmy sunfish (*Elassoma zonatum*) may be extirpated from Indiana, but the species status is unknown. Habitat loss has also caused the local extirpation of spotted darter (*Etheostoma maculatum*), greater redhorse (*Moxostoma valenciennesi*), and northern madtom (*Noturus stigmosus*). Range reductions have influenced the distribution of northern brook lamprey (*Ichthyomyzon fossor*), lake sturgeon (*Acipenser fulvescens*), cisco (*Coregonus artedii*), and gilt darter (*Percina evides*). Currently, five species on the endangered list for Indiana (50%) occur in the Wabash River. As sensitive species have declined in abundance, some species have increased in distribution and relative abundance: tippecanoe darter (*Etheostoma tippecanoe*), harlequin darter (*Etheostoma histrio*), and eastern sand darter (*Ammocrypta pellucida*). Intensive evaluations of the Tippecanoe and Wabash Rivers have shown increasing threats. Perhaps the greatest threat to the aquatic biodiversity of the Wabash River fish assemblage is the influence of exotic fish species, with the impact of the Asiatic carps (grass (*Ctenopharyngodon idella*), bighead (*Hypothalmichthys nobilis*), and silver (*H. molitrix*) carps) of looming concern.

Keywords: Biodiversity, status, threatened and endangered species, alien species

The Wabash River flows through the heartland of the Corn Belt Plain and is perhaps the lifeblood of the midwestern United States. Perhaps no other river has been so prominently mentioned regarding the history of North American ichthyology than the Wabash River. As a result of the influence and allure of this river, more long-term studies of large-river fishes (Forbes & Richardson 1920; Gammon 2000) may have been conducted in the Wabash River than any other North American river. In the lower Wabash River, continuous studies at the same sites have been conducted since 1905 by the State of Illinois (Forbes & Richardson 1905), while in Indiana the middle Wabash River has been studied since 1966 (Gammon 2000).

The Wabash River possesses a rich legacy of ichthyological investigations (Rafinesque 1820; Lesueur 1846; Cope 1868, 1870; Jordan 1877; Jordan & Copeland 1877; Swain 1883; Forbes & Richardson 1905). Perhaps more renowned ichthyologists may have waded in the Wabash River and its major tributaries than in any other North American river.

The purpose of this paper is to describe significant contributions that have been accomplished in the Wabash River drainage in the fields of ichthyology and fisheries biology. This paper describes contributions in the study of fish diversity, patterns in large river structure and function, and current threats to fish assemblage stability.

SIGNIFICANT CONTRIBUTIONS TO ICHTHYOLOGY OF THE WABASH RIVER

Among the most famous ichthyologists and fisheries biologists who have traversed the Wabash River are Samuel Constantine Rafinesque, Charles A. LeSueur, Edwin Drinker Cope, David Starr Jordan, Stephen A. Forbes, Charles H. Gilbert, and James R. Gammon.

Samuel Constantine Rafinesque (1783–1840) was an eccentric naturalist who was born in Galata, a suburb of Constantinople.

Rafinesque came to the United States in 1818, where he settled in Kentucky and collected various kinds of biological specimens including fish, plants, a wide variety of invertebrates, and other vertebrate animals. Rafinesque spent a significant amount of his career studying the fauna and flora of the Ohio River basin, but also evaluated fishes from the Wabash River (Call 1985). Generally, Rafinesque described organisms from memory and published his work in a series of articles. His work culminated in the *Ichthyologia Ohiensis*, which set North American ichthyology back considerably (Rafinesque 1820). Rafinesque, while traveling through the Ohio River valley, befriended James Audubon and lodged at his cabin in Henderson, Kentucky. Legend records that during one of these stays, Rafinesque was awakened by bats flying around the cabin. Rafinesque grabbed Audubon's violin and swatted at the bats, ultimately destroying the violin. Audubon got even with Rafinesque by illustrating hypothetical fishes that represented mixtures of several species. Audubon brought these drawings to Rafinesque, who described them as new species. In part, this was the basis for years of frustration and confusion (Agassiz 1855; Jordan 1876).

Charles Alexandre Lesueur (1778–1846) was considered among the most prominent ichthyologists of the early 19th century. Lesueur was born in France and studied with Professors Culver and Valenciennes from the Museum of Natural History in Paris, France. He came to North America and settled in New York, where he began studies of North American freshwater fishes. He was among the prominent scientists who left the Philadelphia Academy of Science on the "Boatload of Knowledge," which was a group of well-known scientists that relocated to New Harmony by traveling down the Ohio River and settled on the banks of the Wabash River. Lesueur joined the experimental New Harmony socialistic colony around 1820 and was there for a short time. Lesueur studied freshwater fishes of the Wabash River, but due to frustrations with other scientists at New Harmony left the settlement and returned to France before completing his treatise of North American fishes.

Edwin Drinker Cope (1840–1897) was among the first ichthyologists to have described fish from Indiana during explorations of the Virginia territory. Cope was a biologist with the Academy of Natural History in Philadelphia and became famous for the large number of dinosaurs he found. His feuds with Othniel C. Marsh, American Museum of Natural History, were known as the dinosaur wars. Cope, as was true of many scientists of his time, studied all aspects of natural history, including herpetology, ichthyology, and paleontology. It is not clear if Cope may have sampled in Indiana or if he described species that had been sent to him by other collectors, but he described species from the White River near Indianapolis and from the Wabash River near Lafayette (Cope 1867, 1868, 1870). Cope was posthumously recognized by the American Society of Ichthyologists and Herpetologists when they named their journal "Copeia" in his honor.

David Starr Jordan (1851–1931) was perhaps the most influential of all American ichthyologists. He began his career in Indiana and is considered the "Father of modern ichthyology." All current ichthyologists can trace their educational "roots" back to Jordan in some manner. Jordan had an illustrious career that began at Butler University, continued at Indiana University, and terminated at Stanford University. While Jordan was in Indiana, he retraced the footsteps of Rafinesque and unraveled the mystery of many Ohio River fishes (Jordan 1876), and then studied fishes in the White River drainage contributing substantially to the description of new species; and, all the while, training students in the understanding of fishes. Jordan, along with Barton Warren Evermann, co-authored the treatise entitled, "Fishes of North and Middle America," which was considered the definitive study on fishes. Jordan, while at Butler University, was known for his collecting trips and travels across North America instructing students in geology, natural history, and the customs of local people. Jordan's exploits are legendary, and he published extensively with his students. After leaving Indiana, Jordan purchased and had shipped to Stanford University the Indiana University fish collection. This material is currently curated at the California Academy of Science. Jordan conducted extensive studies for the Bureau of Fisheries, the United States Fisheries Commission, and surveyed the marine fishes of Japan, Hawaii, and the southeastern United States. Jordan was

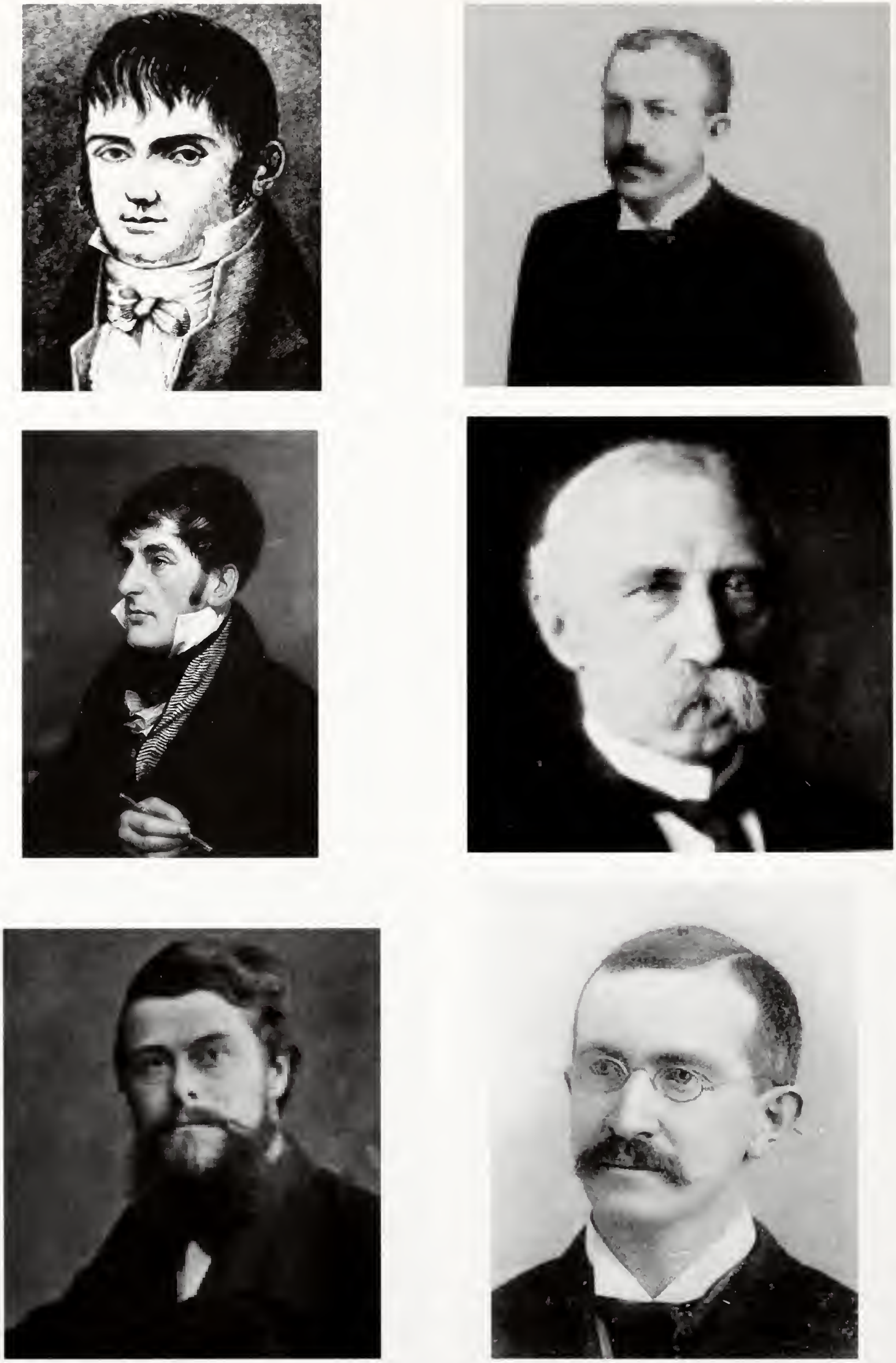

Figure 1.—Ichthyologists and fisheries biologists who made significant contributions to our knowledge of the Wabash River drainage. Top left: Samuel Constantine Rafinesque (1783–1840); Top right: David Starr Jordan (1851–1931); Center left: Charles A. Lesueur (1778–1846); Center right: Stephen A. Forbes (1844–1930); Bottom left: Edwin Drinker Cope (1840–1897); Bottom right: Charles Gilbert (1859–1928).

highly honored and respected by his students and is credited with the development of college majors.

Charles Henry Gilbert (1859–1928) became an early associate of David Starr Jordan. He first met Jordan while a high school student. Gilbert followed Jordan and studied under him first at Butler University. Later, when Jordan went to Indiana University, Gilbert followed him and received his masters and doctorate degrees. Gilbert was the first individual to receive a doctoral degree from Indiana University. He studied fishes in the White River and followed Jordan to Stanford University, where he became a professor in the Department of Zoology. According to some, Gilbert was perhaps best known for his studies of western North American fishes. He was the senior scientist on the voyages of the Albatross, which studied marine fishes and surveyed the Hawaiian Islands. His devotion to Jordan lasted until the end of his life.

Stephen Alfred Forbes (1844–1930) was the founder of the Illinois Natural History Survey. Forbes studied pollution events in the Illinois River, and ultimately conducted surveys of streams and rivers in Illinois that were published in the "Fishes of Illinois" (Forbes & Richardson 1905, 1920). Sites established by Forbes & Richardson that were sampled along the border of the lower Wabash River have contributed significantly to our knowledge of the Wabash River prior to drainage of its extensive wetlands.

James R. Gammon (1936–present) studied fish ecology and the impacts of thermal pollution on the structure and function of fish assemblages in large rivers. Gammon was a Professor at DePauw University. Gammon had significant influence on the development of large river standard operating methods, development of assessment indices, and provided a long-term database that evaluated the middle Wabash River for over 30 years (Gammon 2000).

RESULTS AND DISCUSSION

Fishes of the Wabash River drainage.—The Wabash River has 151 native fish species (Table 1). This could well be the most native fish species of any drainage in the Ohio River basin. The two principal tributaries, the West Fork White River (including the lower White River and the East Fork White River), have 126 species.

The State of Indiana has listed seven "Endangered" and five "Special Concern" species that occur in the Wabash River drainage (Table 1). The State defines endangered species as any animal species whose prospects for survival or recruitment within the state are in immediate jeopardy and are in danger of disappearing from the state. This includes all species classified as endangered by the federal government which are known to occur in Indiana. Special concern is defined as any animal species about which some problems of limited abundance or distribution in Indiana are known or suspected and should be closely monitored. Seven species are classified as State Endangered species, and they include the bantam sunfish (*Lepomis symmetricus*), greater redhorse (*Moxostoma valenciennesi*), lake sturgeon (*Acipenser fulvescens*), northern brook lamprey (*Ichthyomyzon fossor*), channel darter (*Percina copelandi*), and redside dace (*Clinostomus elongatus*), which are found within the Wabash River basin, but may be limited to either single sites or less than 10 locations. The banded pygmy sunfish (*Elassoma zonatum*) may be extirpated from Indiana, but the species status is unknown. The banded sunfish is classified as special concern. Other species occurring in the Wabash River drainage that are classified as special concern include, northern madtom (*Noturus stigmosus*), spotted darter (*Etheostoma maculatum*), tippecanoe darter (*E. tippecanoe*), and western sand darter (*Ammocrypta clara*).

Type locations.—Nine species of fishes have been described from the Wabash River system (Table 2), including two species that were described from the Wabash River proper and another two species from direct tributaries. The shovelnose sturgeon, river redhorse, grass pickerel, and Tippecanoe darter were described from the Wabash River system. The other five species were described from the White River system in the vicinity of Indianapolis.

History of extirpations.—Seven fish species, including a single species that is now extinct, have been extirpated from the Wabash River drainage. The harelip sucker (*Moxostoma lacerum*), known from the Tippecanoe River, was always considered rare; but it is not known what caused the species' demise. Some

Table 1.—Distribution and habitats of fishes of the Wabash River drainage. EP = extirpated; N = native species; NI = possibly introduced, but considered native; EX = extinct; and I = introduced.

	Habitats							Drainage	
Species	Low-Land	Upland	Big River	Stream	Creek	Lacustrine	Subterranean	Wabash River	White River
Petromyzontidae									
Icthyomyzon bdellium	X	X	X	X				N	
Icthyomyzon castaneus	X	X	X	X				N	
Icthyomyzon fossor		X		X	X			N	N
Icthyomyzon unicuspis	X	X	X	X				N	
Lampetra aepyptera		X		X	X			N	N
Lampetra appendix		X		X	X			N	N
Acipenseridae									
Acipenser fulvescens	X		X					N	N
Scaphirynchus platorynchus	X		X			X		N	N
Polyodontidae									
Polyodon spathula	X		X			X		N	N
Lepisosteidae									
Atractosteus spatula	X		X			X		EP	
Lepisosteus oculatus	X		X			X		N	N
Lepisosteus osseus	X	X	X	X				N	N
Lepisosteus platostomus	X		X					N	N
Amiidae									
Amia calva	X		X	X		X		N	N
Anguillidae									
Anguilla rostrata	X		X	X				N	N
Cluepidae									
Alosa chrysochloris	X		X					N	N
Dorosoma cepedianum	X	X	X	X		X		N	N
Dorosoma petenense	X		X			X		I	I
Hiodontidae									
Hiodon alosoides	X		X					N	N
Hiodon tergisus	X		X					N	
Gadidae									
Lota lota	X		X					N	
Salmonidae									
Coregonus artedii	X					X		N	
Umbridae									
Umbra limi	X			X	X	X		N	N
Esocidae									
Esox americanus	X	X		X	X	X		N	N
Esox lucius	X	X		X	X	X		N	
Esox masquinongy	X	X	X			X		I	
Cyprinidae									
Campostoma anomalum		X		X	X			N	N
Carassius auratus								I	I
Clinostomus elongatus		X		X				N	
Ctenopharyngodon idella	X		X			X		I	I
Cyprinella lutrensis	X			X	X			NI	

Table 1.—Continued.

	Habitats							Drainage	
Species	Low-Land	Upland	Big River	Stream	Creek	Lacustrine	Subterranean	Wabash River	White River
Cyprinella spiloptera		X	X	X	X		X	N	N
Cyprinella whipplei		X		X	X			N	N
Cyprinus carpio	X	X	X	X	X	X		I	I
Ericymba buccata		X		X	X			N	N
Erimystax dissimilis		X		X				N	
Erimystax x-punctata		X		X				N	
Hybognathus hayi	X		X	X				N	
Hybognathus nuchalis	X		X	X				N	N
Hybopsis amblops		X		X	X			N	N
Hypophthalmichthys molitrix	X		X					I	I
Hypophthalmichthys nobilis	X		X					I	I
Luxilus chysocephalus		X		X				N	N
Lythrurus fumeus	X			X	X			N	
Lythrurus umbratilis	X	X		X	X			N	N
Macrhybopsis hyostoma	X	X	X	X	X			N	N
Macrhybopsis storeriana	X		X	X				N	N
Nocomis biguttatus		X		X	X			N	N
Nocomis micropogon		X		X	X			N	N
Notemigonus crysoleucas	X			X	X	X		N	N
Notropis amnis	X		X	X				N	
Notropis anogenus	X					X		N	
Notropis ariommus		X	X	X				EP	EP
Notropis atherinoides	X	X	X	X		X		N	N
Notropis blennius	X		X					N	N
Notropis boops		X		X	X			N	N
Notropis buchanani	X		X					N	N
Notropis dorsalis		X		X	X			N	
Notropis hudsonius	X		X	X		X		N	
Notropis photogenis		X		X				N	N
Notropis rubellus		X		X	X			N	N
Notropis shumardi	X		X					N	
Notropis stramineus		X		X	X			N	N
Notropis texanus	X					X		N	N
Notropis volucellus	X	X	X	X		X		N	N
Opsopoeodus emilae	X		X	X	X	X		N	N
Phenacobius mirabilis	X	X		X	X			N	N
Phoxinus erythrogaster		X			X			N	N
Pimephales notatus	X	X	X	X	X			N	N
Pimephales promelas	X	X		X	X			N	N
Pimephales vigilax	X	X	X	X				N	N
Rhinichthys obtusus		X			X			N	N
Semotilus atromaculatus	X	X		X	X			N	N
Castostomidae									
Carpiodes carpio	X	X	X	X				N	N
Carpiodes cyprinus	X	X	X	X				N	N
Carpiodes velifer	X	X	X	X				N	N
Catostomus commersonii	X	X		X	X			N	N
Cycleptus elongatus	X		X					N	N

Table 1.—Continued.

	Habitats							Drainage	
Species	Low-Land	Upland	Big River	Stream	Creek	Lacustrine	Subterranean	Wabash River	White River
Erimyzon oblongus	X	X		X	X			N	N
Erimyzon sucetta	X			X	X	X		N	
Hypentelium nigricans		X		X	X			N	N
Ictiobus bubalus	X		X	X				N	N
Ictiobus cyprinellus	X		X	X		X		N	N
Ictiobus niger	X		X	X				N	
Minytrema melanops	X	X		X	X			N	N
Moxostoma anisurum	X	X	X	X				N	N
Moxostoma carinatum	X	X	X	X				N	N
Moxostoma duquesnei		X		X				N	N
Moxostoma erythrurum		X		X	X			N	N
Moxostoma lacerum		X		X				EX	
Moxostoma macrolepidotum	X	X	X	X				N	N
Moxostoma valenciennesi	X	X	X					N	
Ictaluridae									
Ameiurus catus						X		I	I
Ameiurus melas	X	X		X	X	X		N	N
Ameiurus natalis	X	X		X	X	X		N	N
Ameiurus nebulosus	X	X		X		X		N	N
Ictalurus furcatus	X		X					N	N
Ictalurus punctatus	X	X	X	X		X		N	N
Noturus eleutherus		X		X				N	N
Noturus flavus		X		X	X			N	N
Noturus gyrinus	X	X		X	X	X		N	N
Noturus miurus	X	X		X	X			N	N
Noturus nocturnus	X	X		X	X			N	N
Noturus stigmosus		X		X				N	
Pylodictis olivaris	X	X	X	X		X		N	N
Amblyopsidae									
Amblyopsis spelaea		X					X		N
Aphredoderidae									
Aphredoderus sayanus	X		X	X	X			N	N
Fundulidae									
Fundulus catenatus		X		X	X				N
Fundulus dispar	X			X		X		N	N
Fundulus notatus	X	X		X	X	X		N	N
Poeciliidae									
Gambusia affinis	X			X	X	X		N	N
Atherinidae									
Labidesthes sicculus	X	X		X		X		N	
Menidia berylina	X		X					NI	
Gasterosteidae									
Culaea inconstans	X	X			X	X		N	N
Cottidae									
Cottus bairdii		X		X	X	X		N	N
Cottus carolinae		X		X	X				N
Moronidae									
Morone chrysops	X	X	X	X		X		N	N
Morone mississippiensis	X		X	X		X		N	
Morone saxatilis			X					I	

Table 1.—Continued.

Species	Habitats							Drainage	
	Low-Land	Upland	Big River	Stream	Creek	Lacustrine	Subterranean	Wabash River	White River
Centrarchidae									
Ambloplites rupestris	X	X		X		X		N	N
Centrarchus macropterus	X			X	X	X		N	
Lepomis cyanellus	X	X		X	X	X		N	N
Lepomis gulosus	X	X		X	X	X		N	N
Lepomis humilis	X	X		X	X	X		N	N
Lepomis macrochirus	X	X	X	X	X	X		N	N
Lepomis microlophus	X		X			X		NI?	I
Lepomis miniatus	X			X	X	X		N	N
Lepomis symmetricus	X		X		X	X		EP	N
Micropterus dolomieu	X	X	X	X		X		N	N
Micropterus punctulatus		X		X	X			N	N
Micropterus salmoides	X	X	X	X		X		N	N
Pomoxis annularis	X	X	X	X		X		N	N
Pomoxis nigromaculatus	X	X	X			X		N	N
Elassomatidae									
Elassoma zonatum	X				X	X		EP	
Percidae									
Ammocrypta clara	X	X	X	X				EP	N
Ammocrypta pellucida		X		X				N	N
Crystallaria asprella		X		X				EP	
Etheostoma asprigene	X		X	X		X		N	N
Etheostoma blennioides		X		X	X			N	N
Etheostoma caeruleum		X		X	X			N	N
Etheostoma camurum		X		X				N	N
Etheostoma chlorosoma	X			X	X	X		N	N
Etheostoma exile	X	X		X	X	X		N	
Etheostoma flabellare		X		X	X			N	N
Etheostoma gracile	X			X	X	X		N	N
Etheostoma histrio	X	X	X	X				N	N
Etheostoma maculatum		X		X				N	N
Etheostoma microperca		X			X	X		N	N
Etheostoma nigrum	X	X		X	X	X		N	N
Etheostoma spectabile		X		X	X			N	N
Etheostoma squamiceps		X			X			N	
Etheostoma tippecanoe		X		X				N	N
Perca flavescens	X	X	X	X		X		N	I
Percina caprodes	X	X	X	X	X	X		N	N
Percina copelandi		X		X				N	EP
Percina evides		X		X				N	EP
Percina maculata		X	X		X	X		N	N
Percina phoxocephala		X		X				N	N
Percina sciera	X	X		X	X			N	N
Percina shumardi	X		X	X				N	N
Percina uranidea			X		X			EP	
Percina vigil	X			X				EP	
Sander canadensis	X		X	X		X		N	N
Sander vitreus	X		X	X		X		N	N
Sciaenidae									
Aplodinotus grunniens	X		X	X		X		N	N

Table 2.—List of fish species described from the Wabash River drainage including authority and type location.

Species	Authority	Type locality
Scaphirhynchus platorynchus	Rafinesque 1820	No specific locality, Ohio, Wabash, and Cumberland rivers, seldom reaching as high as Pittsburgh, also in Mississippi and Missouri rivers
Esox americanus	Lesueur 1846	Tributaries of Wabash River near New Harmony
Notropis ariommus	Cope 1868	White River near Indianapolis, Marion County
Moxostoma carinatum	Cope 1870	Wabash River at Lafayette
Noturus miurus	Jordan 1877	White River near Indianapolis
Etheostoma tippecanoe	Jordan & Evermann 1890	Tippecanoe River at Marshland (Delong)
Percina coeplandi	Jordan 1877	White River, 8 km N of Indianapolis
Percina evides	Jordan & Copeland 1877	White River near Indianapolis
Percina sciera	Swain 1883	Bean Blossom Creek, 9 km N Bloomington, Monroe County

speculate that the extinction may have been due to either habitat changes or environmental degradation.

The alligator gar (*Atractosteus spatula*) has not been collected from the Wabash River drainage since the turn of the 19th century. The species had been associated with the extensive riverine wetlands surrounding the Wabash River, but with the draining of these wetlands during the late 19th century, the species has been locally extirpated.

Several darters were last collected from the lower Wabash River near New Harmony near the late 1890s (Gerking 1945). The crystal darter (*Crystallaria asprella*), stargazing darter (*Percina uranidea*), and saddleback darter (*Percina vigil*) are large-river fish that are found on riffle habitats (Page 1983; Kuehne & Barbour 1983). Few riffle habitats remain in the lower Wabash River, perhaps as a result of river meandering.

The popeye shiner (*Notropis ariommus*) and channel darter (*Percina copelandi*) were originally described from the White River near Indianapolis (Cope 1867; Jordan 1877). This shiner has not been collected from the White River since the end of the 19th century (Cope 1868). The channel darter is an inhabitant of large, deep rivers and has not been collected in the White River since being described by Jordan (1877). A single record of the channel darter was published by Carney et al. (1993); however, upon inspection of the specimen at the Illinois Natural History Survey it was observed that the specimen was actually a slenderhead darter (*Percina phoxocephala*) (T.P. Simon & B.E. Fisher unpubl. data).

The banded pygmy sunfish was originally known from the lower Wabash River in the extensive backwater swamps. The species was reported by Forbes & Richardson (1905, 1920), but has not been seen since. Although the species may be still present in cypress swamps along the lower Ohio River, it is doubtful that the species is still present in Indiana. Recent on-going surveys since the early 1990s have not found any specimens. The draining of the extensive backwater wetlands along the lower Wabash River is the probable cause of this species extirpation.

Range changes.—Seven fish species have been either extirpated from the Wabash River drainage or have experienced range reductions. They include the northern brook lamprey (*Ichthyomyzon fossor*), lake sturgeon (*Acipenser fulvescens*), lake herring (*Coregonus artedii*), greater redhorse (*Moxostoma valenciennesi*), northern madtom (*Noturus stigmosus*), spotted darter (*Etheostoma maculatum*), and gilt darter (*Percina evides*). Three species have increased their range, including the eastern sand darter (*Ammocrypta pellucida*), harlequin darter (*Etheostoma histrio*), and Tippecanoe darter (*E. tippecanoe*).

The northern brook lamprey is known in Indiana from the Galena River, Lake Michigan basin, and from a few locations in the Tippecanoe River, Fulton County (unpubl. data). Aggressive lampricide treatment of streams to control sea lamprey (*Petromyzon marinus*) populations in the Lake Michigan

Table 3.—Status of known and reported occurrences of cisco in Indiana lakes including the last reported date from published or actual specimens (based on Pearson 2001).

Lake	County	Last report	Status	Reference
Manitou	Fulton	1901	Extirpated	Blatchley & Ashley 1901
Barbee (=Barber)	Kosciusko	1875	Extirpated	Jordan 1875
Little Tippecanoe (James)	Kosciusko	1955	Extirpated	Frey 1955; Pearson 2001
Oswego	Kosciusko	1955	Extirpated	Frey 1955; Pearson 2001
Secrist	Kosciusko	1975	Extirpated	Frey 1955; Pearson 2001
Tippecanoe	Kosciusko	1955	Extirpated	Jordan 1875; Pearson 2001
Winona (=Eagle)	Kosciusko	1886	Extirpated	Jordan & Evermann 1886
Maxinkuckee	Marshall	1886	Extirpated	Jordan & Evermann 1886

basin may have caused the local extirpation of native non-parasitic lampreys.

Lake sturgeon were once known from the Wabash River near Cayuga and throughout the main channel of the Wabash River (Blatchley 1935). Due to the species' large size and difficulty of collecting individuals from main channel habitats, little is known of the species status in the Wabash River. It is assumed that the species has been locally extirpated from the Wabash River, but a small population exists in the East Fork White River beneath Williams Dam (T.P. Simon, unpubl. data; B.E. Fisher, pers. comm.). This may be the only population remaining in the Ohio River drainage.

The lake herring has seen extensive range reduction as a result of cultural eutrophication and the loss of the thermocline in many glacial lakes (Pearson 2001). The species has been locally extirpated from most of the known lakes within the Tippecanoe River system (Table 3).

The greater redhorse is rare in the Wabash River drainage and was previously known from only a few locations in Vigo County (Whitaker & Wallace 1973) and from the Eel River watershed upstream of Logansport (Braun 1984). Sampling at previously known collection localities in the Wabash River and tributaries (Vigo County) has shown that the species has been locally extirpated. Currently, the species is found only in the Eel River watershed in Indiana and has not been collected anywhere else in the Ohio River drainage.

The northern madtom has not been collected from the Tippecanoe River since the late 1800s (Gerking 1945). The species has been recently reported from the Tippecanoe River, but specimen identity is unconfirmed. As a result, the current status of the species is unknown. The northern madtom has been collected from the mainstem Ohio River near Evansville at water depths of 18.6 m (B.E. Fisher unpubl. data).

The spotted darter was last collected from the Tippecanoe River in 1985 from a large riffle downstream of Winamec, Fulton County (Carney et al. 1993; T.P. Simon unpubl. data). The species has not been collected from the Wabash River drainage, but the species has been found in the East Fork White River downstream of Shoals (B.E. Fisher pers. comm.).

The gilt darter was originally found throughout the West Fork White River from Marion to Morgan County (Marguilles et al. 1980). The type locality for the gilt darter is the West Fork White River near Indianapolis. The gilt darter has been extirpated from its type locality but is considered currently stable, being found only in the middle Tippecanoe River from Rochester to Lake Shafer (B.E. Fisher pers. comm.).

The eastern sand darter has remained stable or increased in distribution throughout the Wabash River, but has not expanded in the White River watershed (B.E. Fisher pers. comm.). The species is found in the Tippecanoe River and from the Wabash River mainstem upstream to the Eel River, including many tributaries. The species is found over clean sand with moderate current.

The harlequin darter was considered to be extirpated from Indiana for more than a century (Whitaker & Gammon 1988). However, in the early 1990s, Simon & Kiley (1993) found the species in the lower White River and upper East Fork White River watershed, as did Greg Seegert (pers. comm.). Harlequin darters are found on woody debris in moderate- to fast-flowing waters. The harlequin darter has been collected continuously from the mouth of the Patoka River up the Wabash River to the mouth of the White River, and continuing upstream of Columbus in the Sugar Creek watershed. The species is currently expanding into the West Fork White River and occurs as far north as Richland Creek (B.E. Fisher pers. comm.).

Finally, the tippecanoe darter has probably not expanded its range greatly, but more efficient sampling techniques have enabled more extensive collection (Simon 2005). Trautman (1980) has shown that abundance in Ohio can change dramatically based on annual recruitment. The Tippecanoe darter is found from the Tippecanoe River from Delong (Marshland) to the mouth with the Wabash River (Jordan & Evermann 1890), and has been collected in the lower East Fork downstream of Williams dam to Shoals (B.E. Fisher pers. comm.).

Threat of alien invasion.—The first wave of alien invasion occurred with the transplant of the common carp (*Cyprinus carpio*) and goldfish (*Carassius auratus*) into North America. These species became established and naturalized after being introduced into the mainstem rivers and streams with the intention that they might become food or game fish. Both species reach very large sizes and contribute to commercial fishery in their native habitats.

The common carp has been introduced throughout North America, and there is not a drainage or state that does not include this species. Carp are ubiquitously found throughout the Wabash River drainage. Goldfish have been much less successful in colonizing the streams and rivers of North America and are nearly absent from the Wabash River drainage. They are typically found only in the most degraded habitats in the White River watershed in the Central Canal in downtown Indianapolis.

The second wave of Asiatic aliens may prove to be much more devastating to native fish species than the first. Four large Asian species have been imported by the aquaculture industry and have escaped into the wild. The grass carp (*Ctenopharyngodon idella*), also known as the white amur, was imported into Alabama and Arkansas from eastern Asia in 1963 to control aquatic vegetation (U.S. Fish & Wildlife Service unpubl. data). An adult grass carp has been reported to eat 45 kg (99.2 lbs) of vegetation per day. The grass carp is widespread in the Wabash and lower White rivers. Individuals have been caught by anglers as far north as Lafayette (Tippecanoe County), and to the junction of the East and West Forks of the White rivers.

The bighead carp (*Hypophthalmichthys nobilis*) was brought to Arkansas in 1972 from eastern China by a private fish farmer to control plankton in culture ponds. The species escaped in the early 1980s. The bighead carp feed near the surface of rivers on organisms such as zooplankton and aquatic insect larvae and adults. Bighead carp have been observed schooling with paddlefish (*Polyodon spathula*). This species is also in direct competition with bigmouth buffalo (*Ictiobus cyprinellus*), gizzard shad (*Dorosoma cepedianum*), all larval and juvenile fishes, and native mussels. Individuals are known to grow to be about 39.5 kg (88 lbs) and 1.2 m (4 ft). Bighead carp have been collected in the middle Wabash River, middle West Fork of the White River, and the lower White River near Petersburg, Gibson County.

The silver carp (*Hypophthalmichthys molitrix*) was brought by an Arkansas fish farmer to the U.S. from Asia in 1973 to control phytoplankton and possibly for use as a food fish. Silver carp have also been used in sewage lagoons to control algae. The silver carp escaped in the early 1980s into the Mississippi River basin. This fish is a very proficient feeder that has gill rakers that are fused into sponge-like porous plates. Silver carp can consume 2–3× their weight in plankton each day. Because of its preferred food items, the silver carp is in direct competition with all native fish larvae and juveniles, adult paddlefish, bigmouth buffalo, gizzard shad, and native mussels. These fish can grow to be over 1 m (3 ft) in length and about 27.24 kg (60 lbs).

The most recent escaped Asian carp is the black carp (*Mylopharyngodon piceus*), which was brought to the U.S. in the early 1970s from eastern Asia. The black carp and grass carp resemble each other except that the black carp has fused pharyngeal teeth that are used in crushing shells of mollusks and crustaceans, the primary food of black carp. In the 1980s, black carp was imported for use as a food fish and to control the spread of trematodes (parasites) in snails at catfish farms. The only known record of escape occurred in 1994 in Missouri, when 30 or more black carp escaped with several thousand bighead carp into the Osage River in Missouri. Black carp have reached the size of 1.29 m (4.3 ft) and over 35.87 kg (79 lbs).

The effect of Asian carp on the North American fish assemblages has still not been fully realized. It is unclear when population numbers from the second invasion will stabilize. Asian carps have the potential of affecting phytoplankton, zooplankton, and molluscan assemblages. In addition, these carps may also change the biomass and structure of native fish assemblages. The four Asian species' prolific spawning capacity and large size can reduce native species biomass.

The Wabash River system has experienced significant physical and biological changes as a result of anthropogenic effects. Drainage of wetlands has caused the loss of alligator gar and possibly the banded pygmy sunfish. Changes in the lower Wabash River have resulted in the extirpation of the crystal darter, stargazing darter, and saddleback darter. Range reduction has affected another seven species. Change in water quality, landscape and land use have reduced native fish species biodiversity and have increased Asiatic alien invaders that have restructured the fish assemblage of the Wabash River drainage. The release and escape of grass, silver, and bighead carp into the Mississippi River has seen these species spread into the lower and middle Wabash River and the lower portions of the East and West Forks of the White River. An unknown impact will be the invasion of the black carp. This species has the potential to cause the destruction of native mollusk species, thus further affecting native drainage ecosystems.

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I want to thank James R. Gammon for his friendship; and on behalf of every fisheries biologist, ichthyologist, and fish ecologist, we extend our appreciation for his significant contributions to our knowledge of the Wabash River fish assemblage. The long-term study of the Wabash River, including aspects of fisheries biology and our understanding of large river biology, has benefited in numerous ways by his dedication. Numerous individuals have contributed to our understanding of the Wabash River, yet so much more needs to be learned. Although this study may have been funded entirely or in part by the U.S. Fish and Wildlife Service, no endorsement by that agency is intended or inferred.

LITERATURE CITED

Agassiz, L. 1855. Synopsis of the ichthyological fauna of the Pacific slope under the command of Captain C. Wilkes, with recent additions and comparisons with eastern types. American Journal of Science and Arts (2nd series), 18(15–16): 71–99.

Blatchley, W.S. 1938. The Fishes of Indiana. Nature Publication Company, Indianapolis, Indiana.

Blatchley, W.S. & G.H. Ashley. 1901. The lakes of northern Indiana and their associated marl deposits. 25th Annual Report Department of Geology & Natural Resources Indiana 1900:31–321.

Braun, E.R. 1984. A fisheries investigation of the Eel River. Indiana Department of Natural Resources, Division of Fish and Wildlife. Indianapolis, Indiana.

Call, A.C. 1985. The Life and Writings of Rafinesque. John P. Morton & Co., Louisville, Kentucky.

Carney, D.A., L.M. Page & T.M. Keevin. 1993. Fishes of the Tippecanoe River, Indiana: An outstanding midwestern stream. Proceedings of the Indiana Academy of Science 101:201–209.

Cope, E.D. 1867. Synopsis of the Cyprinidae of Pennsylvania. Transactions of the American Philosophical Society 13(13):351–399.

Cope, E.D. 1868. On the distribution of fresh-water fishes in the Allegheny region of southwestern Virginia. Journal of the Academy of Natural Sciences, Philadelphia (Series 2), 6 (art. 5):207–247.

Cope, E.D. 1870. Partial synopsis of the fishes of the fresh waters of North Carolina. Proceedings of the American Philosphical Society 16:448–495.

Forbes, S.A. & R.E. Richardson. 1905. The Fishes of Illinois. State of Illinois Natural History Laboratory, Champaign, Illinois.

Forbes, S.A. & R.E. Richardson. 1920. The Fishes of Illinois. State of Illinois Natural History Laboratory, Champaign, Illinois.

Frey, D.G. 1955. Distributional ecology of the cisco (*Coregonus artedii*) in Indiana. Investigations of Indiana Lakes & Streams 4:177–228.

Gammon, J.R. 2000. The Wabash River Ecosystem. Indiana University Press, Bloomington, Indiana.

Gerking, S.D. 1945. Distribution of Indiana Fishes. Investigations of Indiana Lakes & Streams 3:1–137.

Jordan, D.S. 1875. The sisco of Lake Tippecanoe. American Naturalist 1876:135–138.

Jordan, D.S. 1876. Concerning the fishes of the Ichthyologia Ohiensis. Bulletin Buffalo Society of Natural History 3:91–97.

Jordan, D.S. & H.W. Copeland. 1876–1877. Checklist of the fishes of the freshwaters of North America. Bulletin Buffalo Society of Natural Sciences 3:133–164.

Jordan, D.S. & B.W. Evermann. 1886. The food fishes of Indiana. Annual Report Indiana State Board Agriculture for 1885:156–173.

Jordan, D.S. & B.W. Evermann. 1890. Description of a new species of fish from Tippecanoe River, Indiana. Proceedings of the United States National Museum 1890:3–4.

Kuehne, R.A. & R. Barbour. 1983. The American Darters. University of Kentucky Press, Lexington, Kentucky.

Lesueur, C.A. 1846. *Esox vermiculatus*. *In*. Histoire naturelle des poisons. (G. Cuvier & A. Valenciennes, eds.) Tome dix-huitieme. Suite du livre dix-huitieme. Cyprinoides. Livre dix-neuvieme. Des Esoces ou Lucioides Hist. Naturae Poissons *i–xix* + 2 pp. + 1–505 pp.

Marguiles, D., O.S. Burch & B.F. Clark. 1980. Rediscovery of the gilt darter (*Percina evides*) in the White River, Indiana. American Midland Naturalist 104:207–208.

Page, L.M. 1983. Handbook of Darters. T.F.H. Publications, Neptune, New Jersey.

Page, L.M. & B.M. Burr. 1986. Zoogeography of fishes in the lower Ohio–upper Mississippi basin. Pp. 287–324. *In* The Zoogeography of North American Freshwater Fishes. (C.H. Hocutt & E.O. Wiley, eds.) John Wiley & Sons New York, New York.

Pearson, J. 2001. Cisco population status and management in Indiana. Indiana Department of Natural Resources, Division of Fish & Wildlife Indianapolis, Indiana. 23 pp.

Rafinesque, S.C. 1819–1820. Ichthyologia Ohioensis. Reprint edition. 1970. Ames Press, 90 pp. of an *in toto* edition published by W.C. Hunt, Lexington, Kentucky. Of Rafinesque's papers originally published in Western Rev. and Misc. Mag. as follows (*fide* Gilbert 1998:1(1):305–313 (December 1819); 1(2):361–377 (January 1820); 1(3):50–57 (February 1820); 2(4):169–177 (April 1820); 2(5):235–243 (May 1820); 2(6): 299–307 (June 1820); 2(7):355–363 (July 1820); 3(8):165–173 (October 1820); 3(9):244–252 (November 1820); Pagination cited herein per Hunt's edition.

Scott, W. 1931. The lakes of northeastern Indiana. Investigations of Indiana Lakes & Streams 1:61–81.

Simon, T.P. 2005. Life history of the Tippecanoe darter, *Etheostoma tippecanoe* Jordan and Evermann, in the Tippecanoe River, Carroll County, Indiana. Miscellaneous Papers of the Indiana Biological Survey Aquatic Research Center, Number 5. Bloomington, Indiana.

Simon, T.P. & A.L. Kiley. 1993, Rediscovery of the harlequin darter, *Etheostoma histrio* Jordan and Gilbert, in the White River drainage, Indiana. Proceedings of the Indiana Academy of Science 102:279–281.

Swain, J.S. 1883. A description of a new species of *Hadropterus* (*Hadropterus scierus*) from southern Indiana. Proceedings United States National Museum 6 (379):252.

Trautman, M.B. 1980. The Fishes of Ohio. Ohio State University Press, Columbus, Ohio.

Whitaker, J.O., Jr. & J.R. Gammon. 1988. Endangered and threatened vertebrate animals of Indiana, their distribution and abundance. Indiana Academy of Science Monograph 5, Indianapolis, Indiana.

Whitaker, J.O., Jr. & D.C. Wallace. 1973. Fishes of Vigo County, Indiana. Proceedings of the Indiana Academy of Science 82:448–464.

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2006. Proceedings of the Indiana Academy of Science 115(2):149–155

SMALL MAMMALS OF THE WABASH RIVER BOTTOMS

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ABSTRACT. The most abundant terrestrial small mammals in the Wabash River bottomlands in Vigo County, Indiana, in the early 1960's were the house mouse, the white-footed mouse, the prairie deer mouse, and the meadow vole. The white-footed mouse, house mouse and meadow vole were taken at greater rates in the bottoms than in the uplands. The prairie deer mouse and the short-tailed shrew were taken at greater rates in the uplands than in the bottoms. The swamp rabbit (state-endangered) once occurred in several southwestern Indiana counties, but currently occurs along the Wabash River mainly in the north and south portions of Gibson County. The population of swamp rabbits in the state seems to be relatively stable at about 80 animals. The bat community of the lower Wabash River from southern Vigo County south to the Ohio River is particularly interesting. Through 1999, there were 1439 bats, including nine of the 10 species of bats that currently occur in Indiana, captured in the Prairie Creek region of southern Vigo County. By decreasing abundance, the bats are the evening bat (state-endangered), big brown bat, northern myotis, red bat, little brown myotis, eastern pipistrelle, Indiana myotis (federally-endangered), silver-haired bat, and hoary bat. All of these species occur south to the Ohio River. Only female and young evening bats occur in Vigo County, but adult males also occur in Posey County near the Ohio River.

Keywords: Bats, rabbits, rodents, shrews, Wabash River bottoms

Starting in 1962, a series of randomly selected 25 × 25m plots in Vigo County was used to learn about the small mammals of the county (Table 1) (Whitaker 1967). However, the Wabash River flows through Vigo County from north to south, and the data from the river bottoms were not examined separately from the data for the entire county.

In addition, we undertook a study of the bats of the Wabash and Ohio drainages in southwest Indiana (Whitaker & Gummer 2001). As part of this latter study, on 25 July 1994, we mist-netted for bats on lower Prairie Creek in the Wabash River bottoms (Whitaker 1997, 2004) and captured 15 bats of six species, as follows: evening bat (*Nycticeius humeralis*, 6), red bat (*Lasiurus borealis*, 2), big brown bat (*Eptesicus fuscus, 2), eastern pipistrelle, (Pipistrellus subflavus*, 2), northern myotis (*Myotis septentrionalis*, 2), and Indiana myotis (*Myotis sodalis*, 1). This proved to be one of the most productive localities for bats in Indiana, and led to much more study of the bats of the Prairie Creek area.

Twelve species of bats occur or did occur in Indiana, although one species, the southeastern myotis (*Myotis austroriparius*) is apparently extirpated, and the big-eared bat (*Corynorhinus rafinesquii* occurs only accidentally in the state. In addition, the only gray bat maternity colony in the state is at Sellersburg, just north of Louisville. Therefore, it might occur along the Ohio River, but would not be likely along the Wabash River. No evening bats or Indiana myotis were taken along the Ohio (Table 2). The silver-haired bat is not present in summer in Indiana, as it has its young to the north of the state, and it occurs in Indiana only during the spring and fall migrations. No silver-haired bats were captured in the Ohio or lower Wabash valley. Because netting was done in summer, few if any silver-haired bats were expected.

The objectives of this paper are to present information on the Wabash River Bottoms and to compare it with the small mammals (Insectivora, Rodentia) of the uplands of Vigo County, Indiana, and also to compare data on the bats of the Wabash River bottoms from the Prairie Creek area of southern Vigo County, on the lower Wabash River south to the Ohio River, and to those of the Ohio River Valley of southern Indiana. These data can serve as baseline data for future studies.

METHODS

For the small mammal study, a series of 500 randomly-selected, 25 × 25 m plots was

Table 1.—Small mammals trapped in 1962–65 in 54 randomly-selected plots (4050 trap-nights) from the Wabash River bottoms compared to 375 plots (28,125 trap-nights) from the uplands of Vigo County, Indiana.

	Wabash bottoms		Uplands and Vigo County	
	Number of animals	Number per 100 trap-nights	Number of animals	Number per 100 trap-nights
Mus musculus	116	2.9	425	1.5
Peromyscus leucopus	77	1.9	237	0.8
Peromyscus maniculatus bairdii	46	1.1	449	1.6
Microtus pennsylvanicus	21	0.5	5	0.01
Microtus ochrogaster	9	0.2	62	0.2
Blarina brevicauda	3	0.07	23	0.08
Sorex cinereus	3	0.07	1	0.03
Zapus hudsonius	1	0.02	3	0.01
Microtus pinetorum	0	0	12	0.04
Cryptotis parva	0	0	6	0.02
Synaptomys cooperi	0	0	1	0.002
Total	276		1224	

used. They were chosen from among the 1,640,331 possible plots of that size in Vigo County using a random number table. Of these 500 plots, traps were actually set in 429 plots (Whitaker 1967). Most of the other 71 plots could not be studied because they happened to occur where buildings, roads, railroads, bodies of water, or barnyards were located. In three cases, permission to trap was denied. Fifty-four of the plots were in the Wabash River bottomlands, including land in and near the floodplain (Table 1, Fig. 1).

In each plot, 25 snap-back mousetraps baited with peanut butter were set in five lines of five traps, with 5 m between each trap, and 2.5 m between the outer traps and the edge of the plot. Traps were checked each day for three consecutive days, then removed, hence each plot was represented by 75 trap-nights (TN) of effort. Plot sampling occurred between 1962 and 1965 and throughout the year, about four plots per week. Traps in plots were checked for three days after they were set.

The plots were chosen completely at random, and habitats were divided into 15 categories assessed at the time of trapping: upland woods, river bottom woods, brush, brushy field, weedy field, grassy field, pasture, corn, corn stubble, soybeans, soybean stubble, winter wheat, wheat stubble, plowed field, and

Table 2.—Bats of Prairie Creek, the Wabash River basin south of Vigo County, and the Ohio River basin of southwestern Indiana. Posey County was included in the Wabash basin, not the Ohio basin. Actual numbers are given first, the number per netting in parentheses.

	Prairie Creek	Wabash basin	Ohio basin	Total
Number nettings	176	36	37	249
Nycticeius humeralis	558 (3.17)	38 (1.06)	0	596 (2.39)
Eptesicus fuscus	254 (1.44)	30 (0.83)	31 (0.84)	315 (1.27)
Myotis septentrionalis	237 (1.34)	39 (1.08)	26 (0.7)	299 (1.20)
Lasiurus borealis	131 (0.74)	32 (1.17)	45 (1.22)	208 (0.88)
Myotis lucifugus	114 (0.64)	36 (1.0)	13 (0.35)	162 (0.65)
Pipistrellus subflavus	92 (0.52)	21 (0.58)	39 (1.05)	151 (0.61)
Myotis sodalis	49 (0.28)	9 (0.25)	0	58 (0.23)
Lasionycteris noctivagans	3 (0.20)	0	0	3 (0.01)
Lasiurus cinereus	1 (0.006)	3 (0.08)	1 (0.03)	5 (0.02)
Myotis grisescens	0	0	9 (0.24)	9 (0.04)
Totals	1439 (8.15)	208 (5.78)	164 (4.43)	1811 (7.26)

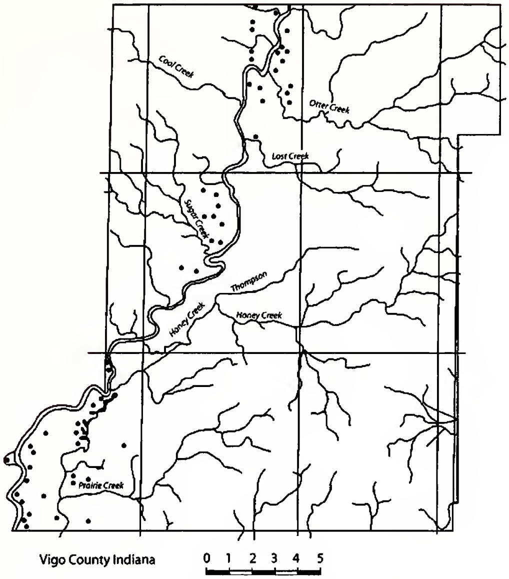

Figure 1.—Randomly-selected small mammal plots (n = 54) in the Wabash River bottoms of Vigo County.

other cultivated fields. Cover was assessed separately for each plot at the time of trapping. In poor cover, the ground was open. A mouse would be exposed all or most of the time it was on the surface. Fair cover was assessed if a mouse would be exposed much of the time but would have some hiding places. In good cover, the ground was generally covered with vegetation and a mouse would be hidden most of the time it was on the surface. Corn, soybean, and wheat stubble, along with plowed ground, normally had poor cover. Corn, wheat, and soybeans might have had poor, fair or good cover depending on the time of year of trapping and also the amount of other vegetation present.

The individual cover assessments were applied in determining the relationship of small mammals to cover. All species showed a positive relationship to herbaceous ground cover except the prairie deer mouse which uses the soil as cover and showed a negative association with cover. There were 54 plots in the Wabash River bottoms as defined by the glacial Wabash River bottoms. Most of these plots were flooded when the Wabash River flooded. There were 375 plots in the rest of Vigo County which were termed the "uplands." More details may be found in Whitaker (1967).

Mist nets were used for bats (Fig. 1), usually over streams, but sometimes in old roads or other areas which might have served as flyways. Nets were normally used for 5 h starting at dusk. Netting occurred in the lower Wabash and Ohio river basins from 1992 to 1999 (Whitaker & Gummer 2001). Netting at Prairie Creek occurred from 1993 through 1997 (Whitaker 1997, 2004). Netting generally occurred one night per site, and between 15 May and 15 August.

RESULTS

Small terrestrial mammals.—The most abundant small mammals in the Wabash bottomlands of Vigo County were the house mouse (*Mus musculus*), the white-footed mouse (*Peromyscus leucopus*), the prairie deer mouse (*Peromyscus maniculatus bairdii*), and the meadow vole (*Microtus pennsylvanicus*) (Table 1). The house mouse, white-footed mouse and meadow vole were taken at significantly greater rates in the bottoms than in the uplands (χ^2 = 34.7, 36.3 and 154, 1 df). The prairie deer mouse occurred at a significantly greater rate on the uplands than in the bottoms (χ^2 = 6.01, 1 df). The short-tailed shrew (*Blarina brevicauda*) was taken at similar rates on the uplands and the bottoms, but the sample size was too small to test. The prairie vole (*Microtus ochrogaster*) was taken at a similar rate in the bottoms and in the uplands. The masked shrew (*Sorex cinereus*) and the meadow jumping mouse (*Zapus hudsonius*) were taken sparingly in the bottoms and in the uplands. The woodland vole (*Microtus pinetorum*), least shrew (*Cryptotis parva*), and the bog lemming (*Synaptomys cooperi*), were taken in low numbers in the uplands, but none were taken in the bottoms. It is noteworthy that three masked shrews were taken in the bottoms and only one was taken in a much greater amount of trapping in the uplands. French (1980) found the masked shrew (*Sorex cinereus*) on the lowlands of Vigo County, and the southeastern shrew (*Sorex longirostris*) on the uplands. This is particularly interesting since to the southeast of Vigo County in the unglaciated hill country—the only part of the state where the masked shrew does not occur—the southeastern shrew occurs mostly on the lower part of the ravines (Cudmore &

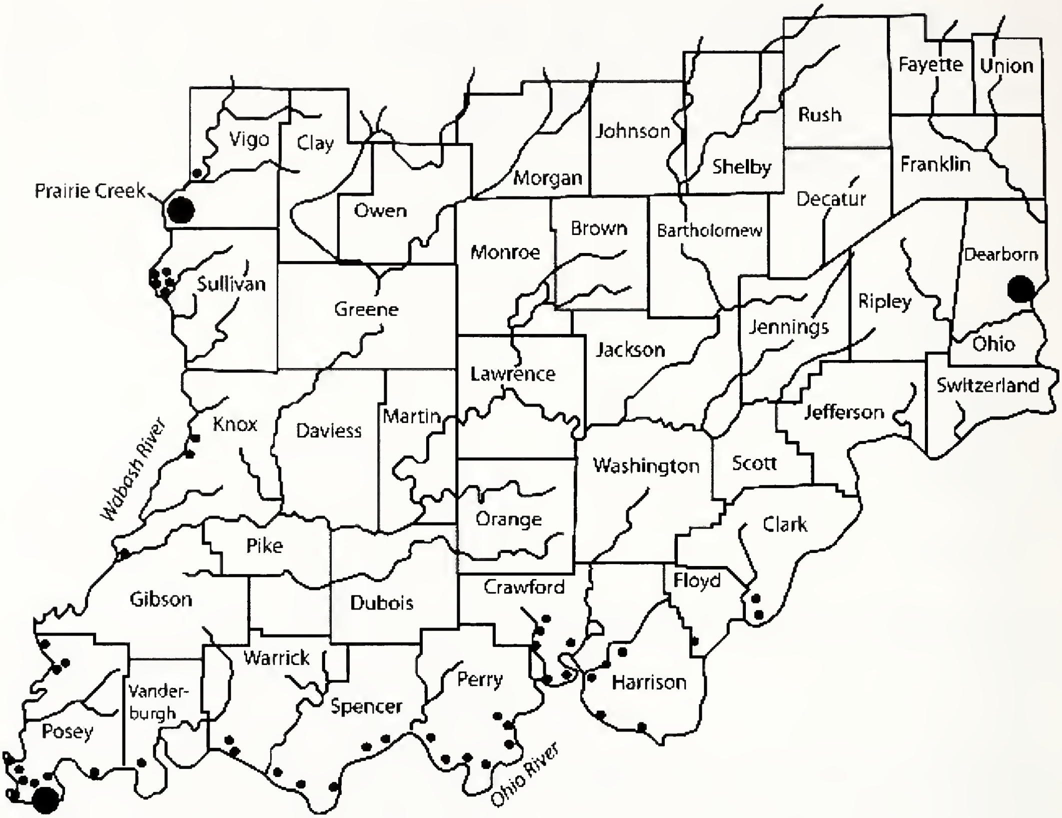

Figure 2.—Localities where mist-netting for bats occurred at Prairie Creek (n = 176) in the lower Wabash River Valley (n = 36) and in the Ohio River Valley (n = 37). Large black circles indicate more than one netting occurred.

Whitaker 1984). The unglaciated hill country is the only part of the state where the pygmy shrew (*Sorex hoyi*) and smoky shrew (*Sorex fumeus*) occur, and they are mainly on the upper parts of the ravines.

The most abundant species of small mammal in Vigo County in the early 1960's was the house mouse (Table 1) (totalling 541), followed by the prairie deer mouse (n = 495). However, the prairie deer mouse occurred at a slightly greater rate in the uplands than in the bottoms. Nearly all of the house mice were taken in weedy or grassy fields or corn or soybeans (Table 3), where there was much herbaceous ground cover (often of grasses, especially foxtail grass, *Setaria faberi*). As soon as the ground cover was removed by mowing or harvesting, the house mice were gone, as indicated by their absence in areas with little ground cover (Whitaker 1967). Presumably they moved to other areas with adequate ground cover. One major change has occurred in farming methods since this study was carried out. In the late 1960's and early 1970's, farmers began to use herbicides in many of the cultivated fields. This has greatly reduced the grassy and weedy plants in the corn and soybeans. We hope to repeat the earlier studies to determine if there have been changes in the small mammal community, and particularly if the house mouse has been reduced as a result of the use of herbicides. All species except the prairie deer mouse were more abundant in greater amounts of cover. The prairie deer mouse occurred at greater rates in less herbaceous ground cover, 1.24/100 trap nights (TN) in good cover, 1.95/100 TN in plots with fair cover, and 2.50/100 TN in plots with poor cover (Whitaker 1967). Deer mice use the soil, rather than vegetation, as cover.

The main species of small mammals were compared by habitat as they occurred in the

Table 3.—Occurrence of the main small mammals in the major habitats of the Wabash River bottoms and uplands in Vigo County, Indiana. (TN = trap-night, 1 trap per 1 night) The data in this table do not agree with those in Table 1 because only plots the major habitats are included.

	River bottoms			Uplands		
	# Plots (TN)	# Animals	#/100 TN	# Plots (TN)	# Animals	#/100 TN
Peromyscus leucopus						
Woods	12 (900)	38	4.2	54 (4050)	65	1.6
Weedy field	8 (600)	18	3.0	21 (1575)	19	1.2
Grassy field	5 (525)	20	5.3	28 (2100)	10	0.1
Corn	12 (900)	0	0	26 (1950)	31	1.6
Corn stubble	6 (450)	1	0.2	44 (3300)	1	0.03
Soybeans	1 (75)	0	0.0	15 (1125)	4	
Plowed field	6 (450)	0	0	42 (3150)	5	0.2
Peromyscus maniculatus						
Woods	12 (900)	0	0	54 (4050)	0	0
Weedy field	8 (600)	10	1.7	21 (1575)	28	0.6
Grassy field	5 (525)	2	0.5	28 (2100)	24	0.2
Corn	12 (900)	13	1.4	26 (1950)	22	1.1
Corn stubble	6 (450)	6	1.3	44 (3300)	38	1.2
Soybeans	1 (75)	1	1.3	15 (1125)	34	3.0
Plowed field	6 (450)	12	2.7	42 (3150)	74	2.3
Mus musculus						
Woods	12 (900)	2	0.2	54 (4050)	0	0
Weedy field	8 (600)	49	8.2	21 (1575)	14	0.9
Grassy field	5 (525)	12	3.2	28 (2100)	62	0.6
Corn	12 (900)	38	4.2	26 (1950)	101	5.2
Corn stubble	6 (450)	0	0	44 (3300)	25	2.2
Soybeans	1 (75)	10	2.2	15 (1125)	68	2.1
Plowed field	6 (450)	0	0	42 (3150)	1	0.03
Microtus ochrogaster						
Woods	12 (900)	0	0	54 (4050)	0	0
Weedy field	8 (600)	0	0	21 (1575)	20	1.3
Grassy field	5 (525)	7	1.9	28 (2100)	18	0.2*
Corn	12 (900)	0	0	26 (1950)	3	0.2
Corn stubble	6 (450)	2	0.4	44 (3300)	0	0
Plowed field	6 (450)	0	—	42 (3150)	0	—
Microtus pennsylvanicus						
Woods	12 (900)	1	0.1	54 (4050)	0	0
Weedy field	8 (600)	3	0.5	21 (1575)	1	0.06
Grassy field	5 (525)	14	3.7	28 (2100)	2	0.02
Corn	12 (900)	0	—	26 (1950)	0	—
Corn stubble	6 (450)	2	0.4	44 (3300)	0	—
Plowed field	6 (450)	0	0.0	42 (3150)	0	0.0
Blarina brevicauda						
Woods	12 (900)	2	0.2	54 (4050)	17	0.42
Weedy field	8 (600)	0	0	21 (1575)	0	0
Grassy field	5 (525)	0	0	28 (2100)	2	0.02
Corn	12 (900)	1	0.1	26 (1950)	0	0.0
Corn stubble	6 (450)	0	0.0	44 (3300)	0	0.0
Plowed field	6 (450)	0	0	42 (3150)	0	0

bottoms and in the uplands (Table 3). The house mouse was more abundant (number per 100 TN) in weedy fields and grassy fields in the bottoms, but was slightly more abundant in corn fields in the uplands than in the bottoms. The white-footed mouse was far more abundant in its main habitats (woods, grassy field, and weedy field) in the bottoms than in the uplands. The prairie deer mouse was more abundant on the uplands (number per 100 TN) than on the bottoms, and this was primarily due to effects from soybeans, as this species occurred at greater rates in the bottoms in all other habitats. There was only one soybean plot in the bottoms.

Bats.—All nine species of bats that were likely to occur in the Prairie Creek area and in the lower Wabash did occur there (Table 2). Of particular interest is the evening bat (*Nycticeius humeralis*). Some 40 years ago there were 10 colonies of evening bats in Indiana and one in adjacent Illinois (Whitaker & Gummer 2003). All were in buildings, and they were spread over southern Indiana. We checked all of the roosts; and, also, we netted near all of them. We located one colony in 1987 in a church in Clay County (Whitaker & Gummer 2003; Clem 1992). All these colonies appeared to be gone as of 1993, and we knew of no evening bats in Indiana. However, on 25 July 1994, we netted 15 bats of six species at Prairie Creek, and these included six evening bats and one Indiana bat, indicating this locality was worthy of more sampling. Since then we have sampled on many more evenings there. The evening bat is the most abundant bat in that community. We radiotagged one of the first ones captured, and checked every building in the area without success. Finally we checked the woods (this is probably the largest woods in the lower Wabash River Valley at about 650 contiguous ha) and found the roost tree. About 350 evening bats came out of the tree that night. From then on, we have not found any more evening bats roosting in buildings in Indiana. It is possible that the big brown bat has out-competed the evening bat for roosts in buildings. Numerous evening bats occur at Prairie Creek, but we netted only females and juveniles there. The evening bat also occurs along the Wabash south to Posey County where it is quite common. However, in Posey County in extreme southern Indiana, there are both male and female adults. It is suspected that extreme southern Indiana, where adults of both sexes occur, is the northern edge of the hibernating range of this species, and we further suspect that they may hibernate in trees there. After the evening bat, the most common species of bat at Prairie Creek was the big brown bat. The big brown bats lived in buildings in the town of Prairie Creek about 5 km to the south. Adults flew from the town to the study area daily, and after the young became volant they established a postmaternity colony there. The third, fourth and fifth most abundant bats in the Prairie Creek community were the northern myotis, the red bat, and the little brown myotis, all relatively common species over much of the state. These were followed by the eastern pipistrelle and Indiana myotis, both of which roosted in the study area. Only three silver-haired bats were captured, along with one hoary bat.

Larger mammals.—Little work has been done specifically on the larger mammals of the Wabash River bottoms. However, mention must be made of swamp rabbits (*Sylvilagus aquaticus*), one of our most endangered mammals in Indiana. The swamp rabbit once occurred in six southwestern Indiana counties; but, currently, nearly all of them occur in the northern (Long Pond) and southern (Pearl Island) portions of Gibson County (Whitaker & Abrell 1986). They used to be a favorite animal for hunting, but the season has been closed for several years. Terrel (1972) found that their main populations were in the vicinity of Cane Ridge (Gibson County). However, those populations were mostly eliminated by the construction of Gibson Lake. In winter, this species often defecates on logs, and Terrel (1972) found populations of about one swamp rabbit per 10 acres (4 ha) of area with rabbit pellets on logs. Using this value the current population appears approximately stable at about 80 rabbits in the state, mostly in Gibson County.

Coyotes (*Canis latrans*) are commonly heard during mist-netting studies at Prairie Creek; beavers (*Castor canadensis*), white-tailed deer (*Odocoileus virginianus*) and raccoons (*Procyon lotor*) are commonly observed in the Wabash River bottoms in the Prairie Creek area.

DISCUSSION

Included in the Wabash Valley are at least 40 (70.2%) of the 57 mammal species occurring in Indiana: the opossum, 5 species of insectivores, 9 species of bats, both species of rabbits, 16 species of rodents, and 7 species of carnivores. Included are one federally-endangered bat (the Indiana myotis) and two state-endangered species (the evening bat and the swamp rabbit). The evening bat has the core of its Indiana population in the woods of the lower Wabash valley, and the entire Indiana swamp rabbit population (an estimated 80 rabbits) occurs along the Wabash mostly in Gibson County.

The study of small mammals from Vigo County using randomly-selected plots was done over 40 years ago. It thus forms baseline data, prior to the widespread use of herbicides, which can be compared to later data. We hope to repeat that study using the same plots to learn of changes since the early 1960's, particularly in view of the use of herbicides. Additional work can be done in the Prairie Creek area and along the entire lower Wabash. For example, we hope to determine whether southwestern Indiana is the northern part of the range of the evening bat, and where the Prairie Creek evening bats spend the winter. Also, we wish to determine if other bat species, such as the red bat, might winter there.

LITERATURE CITED

Clem, P. 1992. Seasonal population variation and emergence patterns in the evening bat, *Nycticeius humeralis*, at a west central Indiana colony. Proceedings of the Indiana Academy of Science 101:33–44.

Cudmore, W.W. & J.O. Whitaker, Jr. 1984. The distribution of the smoky shrew, *Sorex fumeus*, and the pygmy shrew, *Microsorex hoyi*, in Indiana with notes on the distribution of other shrews. Proceedings of the Indiana Academy of Science 93:469–474.

French, T.W. 1980. Ecological relationships between the southeastern shrew (*Sorex longirostris* Bachman) and the masked shrew (*S. cinereus* Kerr) in Vigo County, Indiana. Ph.D. dissertation. Indiana State University, Terre Haute. 54 pp.

Terrell, T.L. 1972. The swamp rabbit (*Sylvilagus aquaticus*) in Indiana. American Midland Naturalist 87:283–295.

Whitaker, J.O., Jr. 1967. Habitat and reproduction of some of the small mammals of Vigo County, Indiana, with a list of mammals known to occur there. Occasional Papers of the C.C. Adams Center for Ecological Studies. Number 16. Western Michigan University. Kalamazoo. 24 p.

Whitaker, J.O., Jr. 1997. Bats of Prairie Creek. Proceedings of the Indiana Academy of Science 105:87–94.

Whitaker, J.O., Jr. 2004. Prey selection in a temperate zone insectivorous bat community. Journal of Mammalogy 85:460–469.

Whitaker, J.O., Jr. & D.B. Abrell. 1986. The swamp rabbit, *Sylvilagus aquaticus*, in Indiana, 1984–85. Proceedings of the Indiana Academy of Science 95:563–570.

Whitaker, J.O., Jr. & S.L. Gummer. 2001. Bats of the Wabash and Ohio river basins of southwestern Indiana. Proceedings of the Indiana Academy of Science 110:126–140.

Whitaker, J.O., Jr. & S.L. Gummer. 2003. Current status of the evening bat, *Nycticeius humeralis*, in Indiana. Proceedings of the Indiana Academy of Science 112:55–60.

Manuscript received 23 May 2006, revised 10 September 2006).

2006. Proceedings of the Indiana Academy of Science 115(2):156–169

CHANGES IN THE CONDITION OF THE WABASH RIVER DRAINAGE FROM 1990–2004

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ABSTRACT. The Wabash River drainage was evaluated based on three hydrologic watershed units that were sampled from 1990–2004 so that patterns in biological integrity and assessment of aquatic life designated uses could be determined. The three units included: 1) the West Fork and lower White River, 2) the East Fork White River, and 3) the remainder of the Indiana portions of the Wabash River system above its confluence with the Ohio River. Targeted sampling was done in each of the three watershed units from 1990–1995, while a random probability sample design was used from 1996–2004. Assessment of the fish assemblage information for the three periods showed increasing biological integrity for each of the three watersheds. The watershed with the highest biological integrity was the East Fork White River, followed by the West Fork White River, and Wabash River. Aquatic life designated uses were met in 76% of the East Fork White River stream miles; 62% of the West Fork and lower White rivers; and 53% of the Wabash River stream miles.

Keywords: Biotic integrity, biological assessment, probabilistic design, Index of Biotic Integrity (IBI)

The mandate of water quality monitoring agencies is to assess the condition of the waters of the United States and to report on their status. As new tools are developed (Morris et al. 2006) and indices are calibrated (Simon 1992; Simon & Stahl 1998; Simon in review), increasingly more accurate assessments of the status of these waters can be generated which will allow for more emphasis to be placed on restoration of vulnerable and threatened systems, as well as protection of high quality waters. Over the last two decades monitoring tools developed in Indiana have focused primarily on the use of biological indicators (Simon 1992; Simon & Dufour 1998; Simon 2006).

An environment that supports an assemblage of organisms similar to that produced by long-term evolutionary processes is considered to have high biological integrity. Biological integrity has been defined as "the ability to support and maintain a balanced, integrated adaptive assemblage of organisms having species composition, diversity, and functional organization comparable to that of natural habitat of the region" (Karr & Dudley 1981; Karr et al. 1986). Human activities often degrade the environment, resulting in a detectable decline in biological integrity.

When comparing all streams in North America, large rivers are disproportionately degraded (Karr et al. 1985; Poff et al. 1997). The loss of biological integrity in these large river systems is the result of widespread land use changes and anthropogenic land scale disturbance. Few studies have evaluated the long-term changes in biological integrity in drainage units as large as the Wabash River, with emphasis on large mainstem rivers (Hughes et al. 2005).

The purpose of the current study was to document changes in three hydrologic watershed units within the Wabash River drainage from 1990–2004. We compared changes during three assessment periods and the status of the watershed based on a stratified probability based approach.

METHODS

Study area.—The Wabash River is the largest northern tributary of the Ohio River and is the longest free-flowing large river east of the Mississippi. For this study, the Wabash River drainage was divided into three watershed study areas based on 8-digit hydrologic units as defined by the U.S. Geological Survey (USGS). The Wabash River and its direct tributaries include the headwater areas from the State of Ohio to its confluence with the Ohio River (Posey County). The other two drainage units include the largest tributaries of the Wabash River, which are the East and West Forks of the White River. Together these three drainage units represent nearly two-thirds of the total area of central Indiana and encompass portions of the Eastern Corn Belt Plain (ECBP), which is primarily rowcrop agriculture, and the Interior River Lowland (IRL), which includes forest landscapes, as well as oil, gas, and coal exploration land uses (Omernik & Gallant 1988).

Study design.—The State of Indiana uses a Probabilistic Monitoring Program as one portion of the state's comprehensive strategy to provide an evaluation of stream water quality and biological integrity in major basins of Indiana. The probability design generates statistically valid estimates of the percent of total stream miles impaired for aquatic life and recreational uses.

Three hydrologic units in the Wabash River drainage were assessed based on a random, stratified probabilistic design (Messer et al. 1991). The Probabilistic Monitoring Program divided the state into nine major watersheds that are sampled once every five years, providing a complete assessment of the entire state.

Sites were generated using U.S. Environmental Protection Agency (USEPA) Environmental Monitoring and Assessment Program (EMAP) selection methods, which used randomly selected sites to assess and characterize the overall water quality and biotic integrity of the study basin (USEPA 1994; USGS 1994). The target population was defined as all perennial streams within the geographic boundaries of Indiana for the basin of interest. "Perennial" for the purpose of the Probabilistic Monitoring Program was defined as water present in at least 50% of the stream reach (reach was defined as 15 times the average wetted width of the stream, minimum 50 m, maximum 500 m). The sample population included all rivers, streams, canals, and ditches as indexed through the USEPA River Reach File 3 excluding marshes, wetlands, backwaters, impoundments, dry and tiled sites. Site selection was stratified to ensure streams of all sizes/orders (Strahler 1952) were sampled allowing for a spatially accurate representation of the various stream sizes (USEPA 1994; USGS 1994).

Table 1.—Total IBI score, integrity class and attributes to define the fish assemblage characteristics in Indiana streams and rivers (modified from Karr et al. 1986).

Total IBI score	Integrity class	Attributes
53–60	Excellent	Comparable to "least impacted" conditions, exceptional assemblage of species.
45–52	Good	Decreased species richness (intolerant species in particular), sensitive species present.
35–44	Fair	Intolerant and sensitive species absent, skewed trophic structure.
23–34	Poor	Top carnivores and many expected species absent or rare, omnivores and tolerant species dominant.
12–22	Very poor	Few species and individuals present, tolerant species dominant, diseased fish frequent.
<12	No fish	No fish captured during sampling.

Three study periods included the baseline study that was conducted from 1990–1995 and two rounds of the probability sampling that included the periods 1996–1999 and 2001–2004.

Field collection.—Fish assemblages were assessed using a variety of electrofishing equipment. Small streams (<3.3 m wetted width) were sampled using either backpack or long-line electrofishing units; wadeable streams (>3.3 m wetted width) were sampled using long-line or tote-barge electrofishing equipment; large river (non-wadeable >2580 km^2 drainage area) and great river (>5956.97 km^2) reaches were sampled using boat mounted electrofishing units. Sampling was conducted along a linear reach of stream based on 15 times the wetted width with minimum distances of 50 m and maximum distances of 500 m (500 m each bank for large rivers). All

Table 2.—Checklist of fish species collected from the three hydrologic units including the Wabash River, West Fork White River, and East Fork White River from three study periods (1990–2004).

	Wabash River			West Fork White River			East Fork White River		
Family, *species,* common name	90–95	96–99	01–04	90–95	96–99	01–04	90–95	96–99	01–04
Petromyzontidae									
Ichthyomyzon castaneus, chestnut lamprey	1	1		2			1	1	4
I. fossor, northern brook lamprey			4						
I. unicuspis, silver lamprey	3			3	4		3		3
Lampetra aepyptera, least brook lamprey				1				1	
L. appendix, American brook lamprey	2	1		2	3		1		1
Acipenseridae									
Scaphirhynchus platorynchus, shovelnose sturgeon	4	1	4						
Polyodontidae									
Polyodon spathula, paddlefish	26								
Lepisosteidae									
Lepisosteus oculatus, spotted gar				7			3		
L. osseus, longnose gar	138	12	2	56			13	1	6
L. platostomus, shortnose gar	159	15	63	30		3	2	5	4
Amiidae									
Amia calva, bowfin	7	4	3	3		1	3	1	1
Hiodontidae									
Hiodon alosoides, goldeye	18								
H. tergisus, mooneye	16						1		
Anguillidae									
Anguilla rostrata, American eel							1		
Clupeidae									
Alosa chrysochloris, skipjack herring				3				1	
Dorosoma cepedianum, gizzard shad	3648	267	319	1276	16	27	393	60	364
D. petenense, threadfin shad	6	5		9			1		

Table 2.—Continued.

Family, *species*, common name	Wabash River			West Fork White River			East Fork White River		
	90–95	96–99	01–04	90–95	96–99	01–04	90–95	96–99	01–04
Cyprinidae									
Campostoma anomalum, central stoneroller	6715	2166	1136	4744	551	1021	2443	809	2425
C. oligolepis, largescale stoneroller	17	130	92	191					
Carassius auratus, goldfish				96	1				
Ctenopharyngodon idella, grass carp			2						
Cyprinella lutrensis, red shiner	11			3					
C. spiloptera, spotfin shiner	2018	2328	418	13,822	258	262	3939	291	872
C. whipplei, steelcolor shiner	512	119	93	208	20		20	202	74
Cyprinus carpio, common carp	630	200	270	221	36	100	65	9	74
Ericymba buccata, silverjaw minnow	840	360	646	1069	147	120	187	305	60
Erimystax dissimilis, streamline chub	3						5		14
E. x-punctatus, gravel chub	3								
Hybognathus hayi, cypress minnow	11								
H. nuchalis, Mississippi silvery minnow	803	82	76	55	12		4	192	22
Hybopsis amblops, bigeye chub	39	295	170	39			161	39	303
H. amnis, pallid shiner	3						2		
Hypophthalmichthys molitrix, silver carp			4						
Luxilus chrysocephalus, striped shiner	900	216	301	762	116	47	849	68	587
L. cornutus, common shiner	6	3					2		
Lythrurus fumeus, ribbon shiner	9	6		3		2			
L. umbratilis, redfin shiner	196	26	126	137	87	3	125	62	70
Macrhybopsis hyostoma, shoal chub	20	1		1					
M. storeriana, silver chub	168	5	2	4		2	3		
Nocomis biguttatus, hornyhead chub	62	35	90	32	4		14	5	41
N. micropogon, river chub	317	143	80	8	4		11		44
Notemigonus crysoleucus, golden shiner	74	9		106	5		26	3	2
Notropis ariommus, popeye shiner				132					
N. atherinoides, emerald shiner	862	666	114	48	18	22	91	37	42
N. blennius, river shiner	242	1625	20	20					
N. boops, bigeye shiner	6		1	1	7		14	11	2
N. buchanani, ghost shiner	3			3			1		
N. heterodon, blackchin shiner	1								
N. heterolepis, blacknose shiner	1								

Table 2.—Continued.

Family, *species*, common name	Wabash River			West Fork White River			East Fork White River		
	90–95	96–99	01–04	90–95	96–99	01–04	90–95	96–99	01–04
N. ludibundus, sand shiner	677	576	574	891	76	86	140	17	280
N. photogenis, silver shiner		1	1	11	9	24	6		35
N. rubellus, rosyface shiner	15	61	98	61	9	2	48	18	44
N. shumardi, silverband shiner	49	81		186			2	7	
N. volucellus, mimic shiner	14	1	259	29	3		7	25	12
N. wickliffi, channel shiner	91	1	13	2					
Opsopoeodus emiliae, pugnose minnow				1			12	4	
Phenacobius mirabilis, suckermouth minnow	702	157	65	477	49	11	165	39	26
Phoxinus eythrogaster, southern redbelly dace	177	59	37	70	38		179	76	
Pimephales notatus, bluntnose minnow	5063	2644	2448	3404	1268	393	1847	1009	802
P. promelas, fathead minnow	106	5	36	23	2	17	3		
P. vigilax, bullhead minnow	364	422	100	2409	29	71	1023	59	331
Rhinichthys atratulus, western blacknose dace	2587	1061	575	489	131	388	556	79	98
Semotilus atromaculatus, creek chub	6177	2247	1899	2482	582	968	1650	650	840
Catostomidae									
Carpiodes carpio, river carpsucker	490	214	127	76	1	34	31	3	37
C. cyprinus, quillback	62	6	15	214		9	10	1	1
C. velifer, highfin carpsucker	16		11	8		1	5		1
Catostomus catostomus, longnose sucker	3								
C. commersoni, white sucker	2441	194	298	1099	282	347	516	59	270
Cycleptus elongatus, blue sucker	85	14	29						7
Erimyzon oblongus, creek chubsucker	139	29	46	16	32	9	48	25	18
Hypentilium nigricans, northern hogsucker	990	370	242	600	192	101	397	27	453
Ictiobus bubalus, smallmouth buffalo	40	2	11	99		2	4	3	27
I. cyprinellus, bigmouth buffalo	21	4	9	2			2	2	6
I. niger, black buffalo	7		14						2
Minytrema melanops, spotted sucker	86	37	31	59	17	9	73	2	32
Moxostoma anisurum, silver redhorse	45	26	12	27			14	3	17
M. carinatum, river redhorse	5	2	4	1			3	1	25
M. duquesnei, black redhorse	145	127	216	182	31	135	67	27	393
M. erythrurum, golden redhorse	234	85	310	248	60	136	173	58	491
M. macrolepidotum, shorthead redhorse	120	14	51	20		5	30	12	39
M. valenciennesi, greater redhorse			1						

Table 2.—Continued.

Family, *species,* common name	Wabash River			West Fork White River			East Fork White River		
	90–95	96–99	01–04	90–95	96–99	01–04	90–95	96–99	01–04
Ictaluridae									
Ameiurus melas, black bullhead	22	1	9	6	5	4	2	5	
A. natalis, yellow bullhead	238	126	128	161	36	63	102	61	48
A. nebulosus, brown bullhead	4	1	2	6		1	3		2
Ictalurus furcatus, blue catfish	24						13		
I. punctatus, channel catfish	605	83	126	164	1	9	156	12	132
Noturus eleutherus, mountain madtom	1	1		36	1		5		
N. flavus, stonecat	47	70	16	16	17		7		12
N. gyrinus, tadpole madtom	24	9	3	2	1	3			3
N. miurus, brindled madtom	7	9	20	6	3	12	4	30	25
N. nocturnus, freckled madtom	4	4		3					
Pylodictus olivaris, flathead catfish	81	41	21	36		11	15	11	43
Esocidae									
Esox americanus, grass pickerel	82	27	52	22	9	29	7	12	39
E. lucius, northern pike				1					
E. lucius x masquinongy, tiger muskie	2								
Umbridae									
Umbra limi, central mudminnow	75	9	193				1	1	1
Salmonidae									
Oncorhynchus mykiss, rainbow trout									1
Aphredoderidae									
Aphredoderus sayanus, pirate perch	21	95	6	1	1		4	15	12
Fundulidae									
Fundulus catenatus, northern studfish							1	6	8
F. dispar, starhead topminnow				3					
F. notatus, blackstripe topminnow	148	148	97	171	103	115	104	46	10
F. olivaceus, blackspotted topminnow		10					18		
Poeciliidae									
Gambusia affinis, western mosquitofish	117	28	13	23	31	207	1		33

Table 2.—Continued.

	Wabash River			West Fork White River			East Fork White River		
Family, *species,* common name	90–95	96–99	01–04	90–95	96–99	01–04	90–95	96–99	01–04
Atherinidae									
Labidesthes sicculus, brook silverside	54	3	9	103	3	3	72		16
Cottidae									
Cottus bairdi, mottled sculpin	1411	838	167	1003	237	238	312	31	118
C. carolinae, banded sculpin		27		15		16			
Moronidae									
Morone chrysops, white bass	45	1	10	13			1		
M. chrysops x saxatilis, wiper		11							
M. mississippiensis, yellow bass	6	2	2	11		7			
M. saxatilis, striped bass				3					
Centrarchidae									
Ambloplites rupestris, rock bass	260	276	223	162	107	41	100	71	203
Centrarchus macropterus, flier								1	
Lepomis cyanellus, green sunfish	1312	765	517	1000	343	338	527	201	243
L. gibbosus, pumpkinseed	6	25		2			8		
L. gulosus, warmouth	17	11	8	8			22	3	30
L. humilis, orangespotted sunfish	121	64	41	85	2	9	1		1
L. macrochirus, bluegill	495	513	254	897	130	633	711	253	692
L. megalotis, longear sunfish	1872	1473	1293	2017	674	395	1427	629	1407
L. microlophus, redear sunfish	27	10	8	32		1	7	1	17
L. punctatus, spotted sunfish	8			6			4		
Micropterus dolomieu, smallmouth bass	176	60	116	145	101	67	78	13	200
M. punctulatus, spotted bass	188	150	123	250	71	67	400	115	227
M. salmoides, largemouth bass	48	48	12	179	11	47	64	24	27
Pomoxis annularis, white crappie	120	6	9	20	4		9	5	34
P. nigromaculatus, black crappie	10	18	13	14		4	1	6	29
Percidae									
Ammocrypta clara, western sand darter				1			8		
A. pellucida, eastern sand darter			1				1		5
Etheostoma asprigene, mud darter	5	12		19		1	28	21	
E. blennioides, greenside darter	938	718	391	417	168	138	438	276	554

Table 2.—Continued.

Family, *species,* common name	Wabash River			West Fork White River			East Fork White River		
	90–95	96–99	01–04	90–95	96–99	01–04	90–95	96–99	01–04
E. caeruleum, rainbow darter	1108	462	488	809	106	444	207	82	380
E. camurum, bluebreast darter	8	10	13						
E. chlorosomum, bluntnose darter		5							
E. flabellare, fantail darter	467	155	153	98	18	118	196	171	57
E. gracile, slough darter	9	9	7	5	1	1		1	
E. histrio, harlequin darter								16	8
E. microperca, least darter	1	2	4				11	13	
E. nigrum, johnny darter	1608	417	518	641	132	595	425	191	328
E. spectabile, orangethroat darter	912	283	287	646	137	632	253	411	138
E. squamiceps, spottail darter	3		12	1					
E. zonale, banded darter		4							
Perca flavescens, yellow perch	13	8							
Percina caprodes, logperch	143	59	36	44	11	21	27	11	72
P. evides, gilt darter	1	2							
P. maculata, blackside darter	33	43	11	35	17	21	42	18	35
P. phoxocephala, slenderhead darter	92	28	10	14		6	4	11	29
P. sciera, dusky darter	41	115	58	19	11	59	58	18	111
P. shumardi, river darter		8							4
Sander canadense, sauger	22	2	7	2			1	2	5
S. vitreum, walleye	8	3	3						
Sciaenidae									
Aplodinotus grunniens, freshwater drum	578	182	164	464		6	14	12	40

representative habitats were sampled within the stream reach. All fish encountered were netted and placed into a live well. At the completion of the sampling, all fish were identified to species, counted, batch weighed by species, and minimum and maximum length recorded. All individuals were inspected for deformities, eroded fins, lesions, and tumor (DELT) anomalies. Fish were identified using regional identification manuals (Gerking 1955; Smith 1973; Trautman 1981), and voucher specimens are curated at the Indiana Biological Survey Aquatic Research Center, Bloomington, Indiana.

Calculations of biological integrity.—The Index of Biotic Integrity (IBI) was used to assess the biological integrity of the stream (Simon 1992; Simon & Dufour 1998; Simon & Stahl 1998; Simon 2006). The IBI is composed of 12 metrics that assess fish assemblage structure, trophic composition (feeding and reproductive guilds), and fish condition and health. The total IBI score, integrity class and attributes help define fish assemblage characteristics. Table 1, modified from Karr et al. 1986, uses total IBI score, integrity class and attributes to define the fish assemblage characteristics in Indiana streams and rivers.

Indiana narrative biological criteria [327 IAC 2-1-3(2)] states that "all waters, except those designated as limited use, will be capable of supporting a well-balanced, warm water aquatic community" (IDEM 2006a). The water quality standard definition of a "well-balanced aquatic community" is "an aquatic community which is diverse in species composition, contains several different trophic levels, and is not composed mainly of strictly pollution tolerant species" [327 IAC 2-1-9(60)] (IDEM 2006a). A stream segment is non-supporting for aquatic life use when the monitored fish assemblage receives an IBI score of less than 35 which is considered poor or very poor (IDEM 2006b).

Statistics and data analysis.—When estimates for characteristics of the entire target watershed are computed, the statistical analysis must account for any loss of stratification or unequal probability selection due to some sites not being sampled (i.e., access denied, impounded, dry, etc.). This method applies a *post-hoc* statistical correction factor (weighting factor) to an unbalanced sample stratification resulting in a corrected probability design (Diaz-Ramos et al. 1996).

The USEPA National Health and Environmental Effects Research Laboratory (NHEERL) in Corvallis, Oregon, created a software program "psurvey.analysis" that is used to adjust the weighting of sites and develop accurate estimates for a measured parameter in a target population. This software program contains functions which calculate the final weight value for each site and estimates the percentage of integrity class for each hydrologic unit in the Wabash drainage (http://www.epa.gov/nheerl/arm/analysispages/techinfoanalysis.htm).

RESULTS & DISCUSSION

Fish assemblage.—Based on surveys of the entire Wabash River, 150 species were found from 1990–2004. This number of species represents 72.1% of the entire fish fauna of Indiana (Simon et al. 2002). We collected 135 species from the Wabash River hydrologic unit, 113 species from the West Fork and lower White River hydrologic unit, and 115 species from the East Fork White River hydrologic unit (Table 2).

Status.—Based on the sampling and IBI results of three hydrologic units that comprise the Wabash River drainage, the Wabash River and tributaries drainage unit has remained relatively stable during the last 15 years. However, the East Fork White River (EFWR) and West Fork White River (WFWR) drainage units show an increase in biological integrity with higher percentages of fair, good, and excellent integrity classes (Table 3). The EFWR had the highest percentage (17%) of excellent streams, while the Wabash River had the lowest (1%). Watershed ranking of sites that met designated uses for aquatic life (IBI Score >35) included EFWR (76%), WFWR (62%), and Wabash River (53%) (Table 3). The Wabash River possessed the highest percentage of poor sites based on biological integrity (36%), followed by the WFWR (27%), and the EFWR (22%).

Wabash River: Three sampling periods included targeted sampling during 1990–1995, and two probabilistic survey periods during 1998–1999, and 2003–2004 (Fig. 1). Surveys of the Wabash River from 1990–1995 resulted in an average IBI score that classified sites as fair (Fig. 1). None of the Wabash River mainstem sites rated as excellent. The frequency

Table 3.—Probability estimates of condition +/− 95% confidence interval for three hydrologic units in the Wabash River drainage in Indiana (CI = confidence interval, n = number of sites).

Wabash and tributaries

	1st cycle (1996–1999)		2nd cycle (2001–2004)		Combined	
Integrity class	95% CI	n	95% CI	n	95% CI	n
Excellent	1% ± 1	2	2% ± 2	2	1% ± 1	4
Good	10% ± 6	13	14% ± 7	17	13% ± 5	30
Fair	46% ± 11	37	35% ± 11	27	39% ± 8	64
Poor	35% ± 11	30	37% ± 12	23	36% ± 8	53
Very poor	8% ± 7	5	12% ± 8	6	11% ± 6	11

East Fork White River

	1st cycle (1996–1999)		2nd cycle (2001–2004)		Combined	
Integrity class	95% CI	n	95% CI	n	95% CI	n
Excellent	1% ± 1	1	22% ± 8	11	17% ± 10	12
Good	9% ± 7	5	20% ± 12	8	16% ± 7	13
Fair	30% ± 15	10	37% ± 16	12	43% ± 12	22
Poor	53% ± 16	14	19% ± 14	6	22% ± 7	20
Very poor	7% ± 9	2	2% ± 3	1	2% ± 2	3

West Fork White River and Lower White River

	1st cycle (1996–1999)		2nd cycle (2001–2004)		Combined	
Integrity class	95% CI	n	95% CI	n	95% CI	n
Excellent	0%	0	6% ± 8	2	3% ± 4	2
Good	12% ± 10	6	15% ± 10	7	14% ± 7	13
Fair	35% ± 15	12	54% ± 17	18	45% ± 12	30
Poor	48% ± 17	12	8% ± 7	4	27% ± 11	16
Very poor	5% ± 8	1	17% ± 12	5	11% ± 7	6

distribution for each of the IBI condition categories from 1990–1995 included good–excellent (3.6%), good (7.1%), good–fair (14.3%), fair (32.1%), fair–poor (21.4%), poor (17.9%), and very poor (3.6%). Biological integrity for the Wabash River mainstem was low in 1993 from Fountain County to Posey County (Simon & Stahl 1998), possibly influenced by prolonged early summer flooding (Gammon & Simon 1998). For the Wabash River mainstem, the lowest IBI scores occured near old Grand Rapids dam (IBI = 22); and there was a large depression in biological integrity along Vermillion County down river to northern Vigo County (Simon & Stahl 1998). Overall, streams in the watershed improved in the excellent and good condition categories during 1998–99, but categories that failed to meet aquatic life designated uses also increased (Table 3). Continued improvements were observed during 2003–2004 with increases in excellent and good categories, and declines in the fair condition category (Fig. 1). Unfortunately, the poor and very poor condition categories also increased (Table 3). The three frequency distribution curves of total IBI score for the Wabash River watershed over three survey periods show increases in the fair and good integrity classes (ranging from 35 to 53) (Fig. 4).

East Fork White River: Biological integrity increased in the EFWR from 1990-2002 (Fig. 2). During 1990–1995, the fish assemblage conditions ranged from poor–very poor (IBI = 25) to good (IBI = 51). The frequency distribution was: good (16.7%), fair (11.1%), fair–poor (50.0%), poor (16.7%), poor–very poor (5.6%). Sampling conducted during 1997

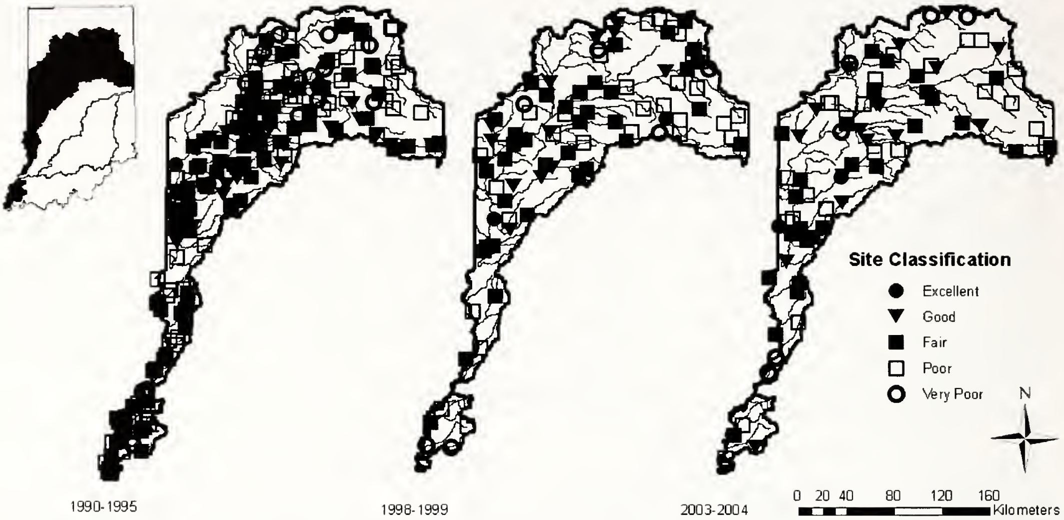


Figure 1.—Status of the Wabash River hydrologic unit based on three survey periods; 1990–1995, 1998–1999, and 2003–2004.

produced similar results to the 1990–1995 period (Fig. 2), with the only difference being an increase in the amount of poor condition sites. During 2002, excellent and good condition sites increased in frequency and poor and very poor condition sites decreased (Table 3). Overall, there were fewer poor sites in 1990–1995 than in both 1997 and 2002. However, more good and excellent integrity classes were found in 2002 than in 1990–1995 and 1997 (Fig. 5).

West Fork White River: Biological integrity in the WFWR and lower White River improved with the largest increases occurring between the poor and fair integrity categories (Fig. 3). During 1990–1995, an increase in biological integrity was observed downstream from the East and West Fork junction to the mouth of the lower White River (Simon 1992). The condition of fish assemblages in the lower White River (1990-1995) ranged from poor to fair (IBI = 27–44), and IBI

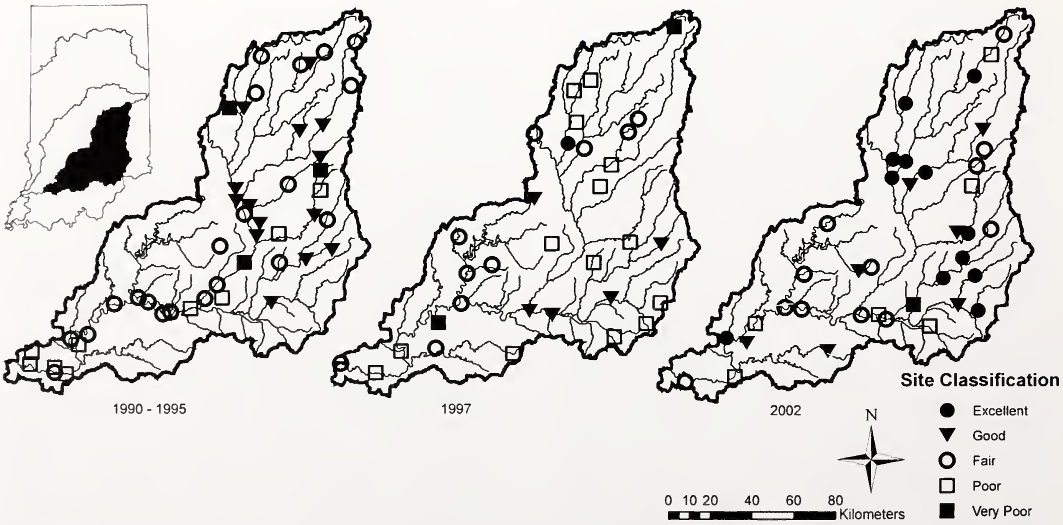


Figure 2.—Status of the East Fork White River hydrologic unit based on three survey periods; 1990–1995, 1997, and 2002.

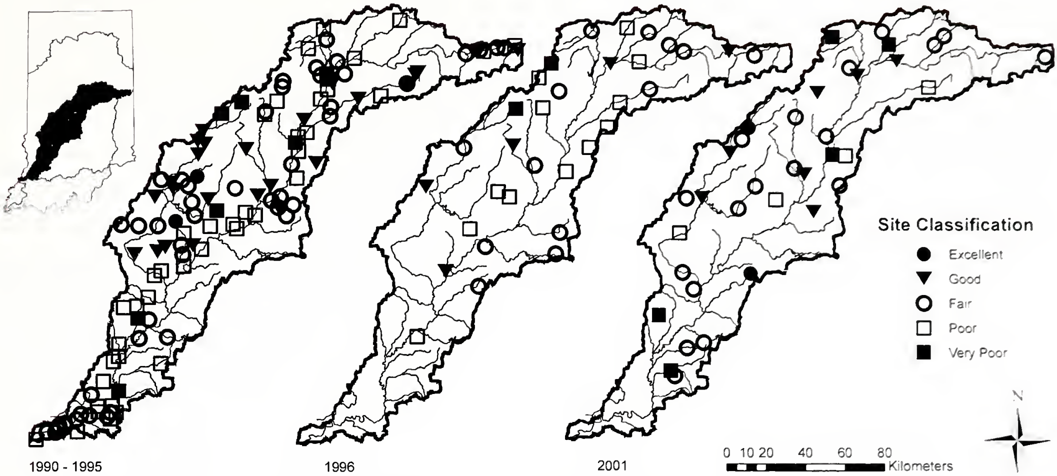


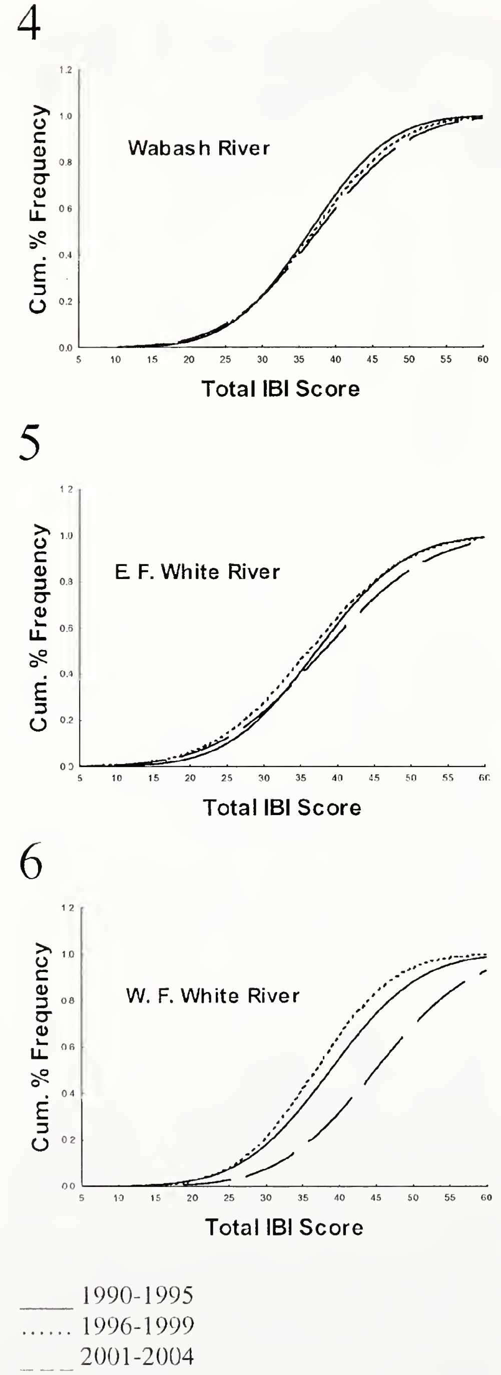
Figure 3.—Status of the West Fork White River hydrologic unit based on three survey periods: 1990–1995, 1996, and 2001.

scores approximated a normal curve with a frequency distribution including, fair 31.3% (*n* = 5), fair–poor 37.5% (*n* = 6), and poor 31.3% (*n* = 5) (Simon 1992). The condition of the fish assemblages in the WFWR (1990–1995) ranged from poor–very poor (IBI = 24) to good (IBI = 46), and the IBI frequency distribution for the 1990–1995 period for the WFWR included: good (5.6%), fair (11.1%), fair–poor (16.7%), poor (22.2%), and poor–very poor (33.3%). During 1996, the biological integrity of the WFWR watershed improved with the increase of the good and fair categories and the decline of the very poor category (Table 3). The frequency distribution of total IBI scores for the West Fork and lower White rivers over the three survey periods indicates a decrease in fair and good integrity classes from 1990–1995 to 1996. However, the high integrity classes rebound in 2001 to levels greater than those seen from 1990–1995 and 1996 (Fig. 6).

Assessment of the three watershed units.—The benefit of the random probability design was a narrower confidence interval for estimated parameters with increasing number of data points; however, this assumes that no changes in water quality affected the biological assemblages (Messer et al. 1991). Assessments of each watershed can be evaluated based on either each of the three time periods or based on a combination of the random probability design sites during each of the two sample rounds (Table 3).

Each watershed estimate reflects a high degree of confidence; however, combination of the data for the ten year period from 1996–2006 can be used to determine trends in aquatic life designated uses. Based on the combined assessment conditions, the Wabash River watershed unit has about 53% of all stream miles meeting aquatic life designed uses: EFWR has 76% of all stream miles meeting aquatic life designated uses (IBI > 35); and WFWR has 62% of all stream miles meeting aquatic life designated uses (Table 3). The EFWR has 33% of all stream miles classified as either good or excellent based on biological integrity, while the WFWR has 17% of stream miles and the Wabash River has 14% classified as good or excellent. The Wabash River had 47% of stream miles failing aquatic life designated uses (classified as poor or very poor), WFWR had 38% failing, and EFWR had 24% as either poor or very poor (Table 3).

An increasing need for Water Quality agencies to report on the entire waters of the nation requires monitoring and assessment tools that can be used to provide accurate classification of water resources. The Wabash River drainage is perhaps one of the most important waters in the State of Indiana. Water quality agencies are increasingly challenged with the responsibility for providing clean water and for restoring the biological integrity of the nation's surface waters. The use of a probabilistic sample design allows all waters to be clas-



Figures 4–6.—Cumulative percent frequency distribution of total IBI scores. 4. Wabash River watershed; 5. East Fork White River watershed; 6. West Fork and lower White River watershed. (Solid line = Ecoregion data: 1990–1995, Dotted line = 1st round probabilistic: 1996–1999, Dashed line = 2nd round probabilistic: 2001–2004.

sified and accurate reporting and inventory to be classified. Trends in biological integrity can be followed as management and restoration programs are implemented.

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LITERATURE CITED

Diaz-Ramos, S., D.L. Stevens, Jr. & A.R. Olsen. 1996. EMAP Statistical Methods Manual. EPA/620/R-96/002, U.S. Environmental Protection Agency, Office of Research and Development, NHEERL-Western Ecology Division, Corvallis, Oregon.

Gammon, J.R. & T.P. Simon. 2000. Variation in a great river index of biotic integrity over a 20-year period. Hydrobiologia 422/423:291–304.

Gerking, S.D. 1955. Key to the fishes of Indiana. Investigations of Indiana Lakes and Streams 4: 49–86.

Hughes, R.M., J.N. Rinne & B. Calamusso. 2005. Historical changes in large river fish assemblages of the Americas. American Fisheries Society Symposium 45. Bethesda, Maryland.

IDEM (Indiana Department of Environmental Management). 2006a. Title 327 of the Indiana Administrative Code, Indiana Environmental Rules: Water, Indiana Department of Environmental Management, Indianapolis, Indiana. http://www.in.gov/legislative/iac/iac_title?iact=327

IDEM (Indiana Department of Environmental Management). 2006b. Indiana Integrated Water Monitoring and Assessment Report 2006. B-001-OWQ-A-00-06-R3. (Jody Arthur, ed.). Office of Water Quality, Indiana Department of Environmental Management, Indianapolis, Indiana. http://www.in.gov/idem/programs/water/305b/index.html

Karr, J.R. & D.R. Dudley. 1981. Ecological perspective on water quality goals. Environmental Management 5:55–68.

Karr, J.R., L.A. Toth & D.R. Dudley. 1985. Fish communities of midwestern rivers: A history of degradation. BioScience 35:90-95.

Karr, J.R., K.D. Fausch, P.L. Angermeier, P.R. Yant & I.J. Schlosser. 1986. Assessing Biological Integrity in Running Waters, a Method and its Rational. Illinois Natural History Survey, Special Publication 5.

Messer, J.J., R.A. Linthurst & W.S. Overton. 1991. An EPA program for monitoring ecological status and trends. Environmental Monitoring and Assessment 17:67–78.

Morris, C.C., T.P. Simon & S.A. Newhouse. 2006. A local-scale *in situ* approach for stressor identification for biologically impaired aquatic systems. Archives of Environmental Contamination and Toxicology 50(3):325–334.

Omernik, J.M. & A.L. Gallant. 1988. Ecoregions of the upper midwest states. EPA/600/3-88/037. U.S. Environmental Protection Agency, ERL, Corvallis, Oregon.

Poff, N.L., J.D. Allan, M.B. Bain, J.R. Karr, K.L. Prestegaard, B.D. Richter, R.E. Sparks & J.C. Stromberg. 1997. The natural flow regime: A paradigm for river conservation and restoration. BioScience 47:769–784.

Simon, T.P. 1992. Biological criteria development for large rivers with an emphasis on an assessment of the White River drainage, Indiana. EPA 905/R-92/006. U.S. Environmental Protection Agency, Region 5, Chicago, Illinois.

Simon, T.P. 2006. Evaluation and assessment of fish assemblages near electric generating facilities: with emphasis on review of discharge submitted data, development of standard operating procedures, and traveling zone assessment. U.S. Department of the Interior, Fish and Wildlife Service, Biological Services Program and Division of Ecological Services, Bloomington, Indiana.

Simon, T.P. 2006. Development, calibration, and validation of an Index of Biotic Integrity for the Wabash River. Proceedings of the Indiana Academy of Science 115:170–186.

Simon, T.P. & R.L. Dufour. 1998. Development of an Index of Biotic Integrity expectations for the ecoregions of Indiana. V. Eastern Corn Belt Plain. EPA 905-R-96-004. U.S. Environmental Protection Agency, Region 5, Chicago, Illinois.

Simon, T.P. & J.R. Stahl. 1998. Development of an Index of Biotic Integrity expectations for the Wabash River. EPA 905/R-96/006. U.S. Environmental Protection Agency, Water Division, Chicago, Illinois.

Simon, T.P., J.O. Whitaker, Jr., J.S. Castrale & S.A. Minton. 2002. Revised checklist of the vertebrates of Indiana. Proceedings of the Indiana Academy of Science 111(2):182–214.

Smith, P.W. 1973. The Fishes of Illinois. University of Illinois Press, Champaign, Illinois. 314 pp.

Strahler, A.N. 1952. Dynamic basis of geomorphology. Geological Society of America Bulletin 63:923–938.

Trautman, M.B. 1981. The Fishes of Ohio. Ohio State University Press, Columbus, Ohio. 782 pp.

USEPA (U.S. Environmental Protection Agency). 1994. Environmental monitoring and assessment program, surface waters and Region 3 regional environmental monitoring and assessment program, 1994 pilot field operations and methods manuals for streams. EPA/620/R-94/004. (Donald J. Klemm and James M. Lazorchak, eds.). Bioassessment and Ecotoxicology Branch, Ecological Monitoring Research Division, Environmental Monitoring Systems Laboratory, U.S. Environmental Protection Agency, Cincinnati, Ohio.

USGS (U.S. Geological Survey). 1994. Report of the Interagency Biological Methods Workshop. Open-file report 94-490. (Martin E. Gurtz and Thomas A. Muir, eds.). U.S. Geological Survey, Raleigh, North Carolina.

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2006. Proceedings of the Indiana Academy of Science 115(2):170–186

DEVELOPMENT, CALIBRATION AND VALIDATION OF AN INDEX OF BIOTIC INTEGRITY FOR THE WABASH RIVER

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ABSTRACT. Fish assemblage data were collected using daytime electrofishing during 1993–2001 from 275 river reaches found throughout the Interior River Lowland and Eastern Corn Belt Plain ecoregions to construct, test, and apply an index of biotic integrity (IBI). The index was developed from a rapid assessment procedure that was used to assess the environmental quality of large and great river ecosystems in the state. The reference condition was based on 275 sites that were representative of the Wabash River, but were not pristine or least-impacted. These sites were not randomly chosen, but met specific least-impacted criteria to develop the IBI. We used another 36 sites exposed to point-source discharges to test the index. Prior to sampling, sites were classified as "least-impacted" or as affected by point source pollution from industrial discharges. Of the 24 potential IBI metrics considered, 12 metrics were chosen based on statistical relevance for large and great rivers. For the test subset, the least-impacted sites had significantly higher mean scores and lower temporal variation than the point-source site classification, showing they possessed the best ecosystem quality. Point-source sites had the lowest means and most variable scores, signifying degraded ecosystem quality. Least-impacted sites had the highest IBI scores and the lowest variability, while representative sites typical of agricultural land uses had slightly but not significantly worse scores. Regional estimates of stream conditions showed that 42% of the stream reaches in the Interior River Lowland ecoregion had fish assemblages in poor or fair ecological condition, while large-river reaches in the Eastern Corn Belt Plain ecoregion had 36% fair and 23% good.

Keywords: Biological integrity, reference condition, IBI, Interior River Lowland, Eastern Corn Belt Plain

The index of biological integrity (IBI) is a multimetric index that integrates structure, composition, trophic ecology, and reproductive attributes of fish assemblages at multiple levels of ecological organization (Karr 1981; Karr et al. 1986; Simon & Lyons 1995; Simon 1999). Indices of biological integrity can be viewed as a family of indices for rating the health of an aquatic ecosystem (Simon 2001). These indices provide a valuable framework for assessing the status and evaluating the restoration of aquatic communities (Fausch et al. 1990; Karr & Chu 1999; Simon et al. 2003). Standard procedures are used to compare existing biological conditions in order to assess the current status of the biota.

Indices of biotic integrity have been widely based on fish assemblages in "wadeable" streams, but applications to large and great warm water rivers are few (Simon & Lyons 1995; Hughes & Oberdorff 1999; Emery et al. 2003). Simon & Stahl (1998) calibrated an IBI for the Wabash River. This calibration was a preliminary index that was based on a limited number of sites and only a portion of the river from Lafayette (Tippecanoe County) to Wabash Island (Posey County). Gammon (2000) calibrated an index for the middle Wabash River, but this calibration was not based on an entire fish assemblage assessment; rather it focused on large, long-lived fish species. The State of Illinois does not have a large-river calibration for their water monitoring program.

In this paper, an IBI is presented that is designed to assess the quality of fish assemblages in the Wabash River. The index was developed using a large statewide database of standardized fish assemblage samples from numerous reaches of varying human impact. An objective procedure was followed to select and score the metrics that comprise the IBI, choosing metrics that represent a variety of the structural, compositional, and functional attributes of large and great rivers (Karr & Chu 1999). The index was then validated with independent data from 36 other river reaches that had anthropogenic disturbances, using as validity criteria the accurate and precise ranking of these other reaches in accordance with their degree of environmental degradation based on water quality, habitat, and use measures. Finally, this IBI was applied to the entire dataset to assess the relative effects of human impacts on river health.

METHODS

Survey design.—Between 1993 and 2001, teams of U.S. Environmental Protection Agency (USEPA), U.S. Fish and Wildlife Service, Indiana Department of Environmental Management, and Indiana Department of Natural Resources professionals sampled 275 large and great river (as defined by Simon & Emery 2000) sites as part of routine monitoring on the Wabash River. The Wabash River includes sites in wadeable stream (<2590 km^2), large- and great river categories. Data used for this project were part of the USEPA's ecoregion project in Indiana (Simon & Stahl 1998), probabilistic assessment for water quality impairment, and monitoring of sport fishes in the Wabash River (Fig. 1). Sampling protocols followed boat electrofishing methods developed by USEPA (1988). In response to criticisms of the Simon & Stahl (1998) paper, large-river criteria development in the Wabash River (EA Engineering, Science, and Technology, Inc. 1999) were reassessed by external peer review, and comments were responded to by Simon & Stahl (2001). The arguments presented in EA Engineering, Science, and Technology, Inc. (1999) were not found to be credible by the external review panel. Protocols, data, and analysis of results were found to be consistent and reproduceble. The conclusion of the external peer review panel was fully supported by both the State of Indiana and the U.S. Environmental Protection Agency.

The Wabash River traverses two ecoregions in Indiana, including the Interior River Lowland and the Eastern Corn Belt Plain (Omernik & Gallant 1988). The Interior River Lowland (IRL) extends from central Indiana along the Wabash River floodplain to the Ohio River and includes the Mississippi River floodplain. The IRL has varied land use including forestry, diverse cropland agriculture, orchards, livestock production, and oil and gas production. The IRL consists of dissected glacial till plains, which are covered by thick mantle loess, rolling narrow ridgetops, and hilly to steep ridge and valley slopes. Woods et al. (1995) subdivided the ecoregion into two subregions that include the area along the Wabash River floodplain to the White River mouth. The Eastern Corn Belt Plain (ECBP) extends from Lafayette to the river's headwaters in Ohio. The ECBP consists of gently rolling glacial till plain, which is broken by moraines, kames, and outwash plains.

Large rivers are defined as drainage units with watersheds greater than 2590 km^2 (1000 mi^2) but less than 5957 km^2 (2300 mi^2) (Simon & Emery 2001), which are effectively sampled using a boat-mounted electrofishing unit. Great rivers include drainage areas greater than 5957 km^2. Following the definition of Lyons et al. (1996) and Mundahl & Simon (1999), the thermal classification for all portions of the Wabash River is warmwater, which means that summer temperatures are too warm to allow the survival of salmonid fishes. Site selection was chosen to maximize different locations along the Wabash River so that various river reaches incorporating different sizes along the regional gradient were sampled. These sites are representative of the condition of the Wabash River; however, sites were picked to deliberately encompass the full range of natural habitat and flow conditions that exist among the Wabash River. The inclusion of the entire suite of sites enables the entire range of conditions to be used to develop both negative and positive metrics. Also, inclusion of sites were selected so that all geographic portions of the drainage were included. By including drainage areas ranging from 1139.6 to 85,231.7 km^2, we provide data from sites that are smaller than typical large-river sites. Site information does not suggest that this is a violation of the River Continuum Concept, since these sites do not reflect an accretion of data sufficient to warrant a drainage area metric calibration. By testing ecoregion and drainage area hypotheses, this enables the creation of a single IBI that does not warrant unnecessary separation of expectations based on ecoregion or size. Although the literature shows that small headwater (<54 km^2) and wadeable streams (>54–2590 km^2) demonstrate a strong species area relationship with drainage area, the size of the main stem Wabash River data used in this study is clearly larger than these size categories; thus it is not surprising that a drainage area calibration correction was not warranted.

A five step process in IBI development was followed, including validation, and application that was modified by Lyons et al. (2001) after the recommendations in Hughes et al. (1998) and Karr & Chu (1999). First, an appropriate sampling methodology was identified and tested. Second, this methodology was used to collect fish assemblage data in a standardized manner from river reaches across the two ecoregions. Some reaches had minimal human impact (least-impacted), while others had varying amounts of different types of human impact from point and non-point source pollution (impacted). Third, we used our fish assemblage data to evaluate potential metrics and develop an IBI. We used data from our least-impacted sites to characterize relatively high-quality fish communities and to investigate the influence of natural factors on community attributes. We contrasted data from least-impacted sites with data from degraded impacted sites to quantify the metric range and sensitivity to human impacts. We then selected final metrics, developed metric scoring criteria, and completed the IBI. Fourth, this IBI was tested with a new set of independent field data that had not been used in the development phase. Finally, IBI scores were compared and ratings among river reaches that had been grouped by type of human impact in order to assess the relative effect of each impact on biotic integrity.

Study area.—Sampling on the Wabash River included 275 large and great river sites collected between 1993 and 2001 for the development of the reference condition, and an independent set of 36 point-source sites collected during 2002 and 2005 was used to validate the index (Fig. 1). The Wabash River extends from the headwaters in Ohio to the mouth of the river at Wabash Island. The Wabash River is the longest free-flowing river east of the Mississippi River and is the largest northern tributary of the Ohio River. The river begins in northwestern Ohio in the Eastern Corn Belt Plain and flows west to southwest; the river bends and flows south through the Interior River Lowland. The Wabash River at the Indiana state line is between 678.6 km^2 (262 mi^2) to 85,236.9 km^2 (32,910 mi^2) at the junction with the Ohio River. Land uses in these areas are principally dominated by agriculture, with some urban, and forested areas.

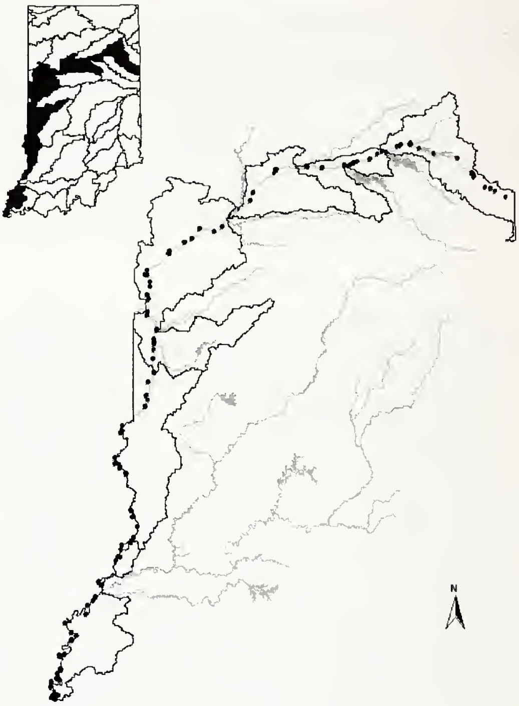

Figure 1.—Distribution of sites sampled as part of the development, validation, and application of an Index of Biotic Integrity for the Wabash River in Indiana.

Data collection.—Daytime fish assemblage sampling was done along a 500 m river reach at each site, based on time criteria using boat-mounted, pulsed-DC electrofishing equipment. Preliminary sampling to establish standard operating procedures were conducted between 1988 and 1990 (Davis & Simon 1989; Simon 1991; Simon & Saunders 1999). Data from this preliminary sampling were not used in IBI development, validation, or application. Large-river (>2509.3 km^2 and <5957 km^2 drainage area) and great river (>5957 km;^{2} drainage area) sites were sampled using a Smith-Root DC mounted electrofishing unit in a jon boat (Simon & Sanders 1999). The boat electrofishing method of U.S. Environmental Protection Agency was used by all agencies, with the only exception being that the state Department of Natural Resources added two seine hauls at each sampling site to better quantify small non-game minnow and darter diversity. A validation of this approach was conducted by repeat sampling of five sites that were sampled using this procedure by DNR. We used an ANOVA to compare differences between metric results and total IBI score for each site. No significant difference was observed between DNR electrofishing + seine samples compared to electrofishing only results. The addition of seining to the standard method by DNR personnel was to ensure that total catch included small nongame species in order to compensate for inherent personnel bias towards large game species. Easily recognized species, including sport fish were identified and released. Voucher specimens of smaller individuals of each species and unidentified specimens were retained for museum verification. Collections were archived at the Indiana Biological Survey, Division of Fishes, Aquatic Research Center, Bloomington, Indiana.

A 500 m reach length is the point distance that has been shown to be representative of a large-river habitat cycle (Simon & Sanders 1999). The adequacy of our stream length criteria was tested by sampling three continuous 500 m segments, for a total of 1500 m. This distance ranged from 2–40× the wetted stream width. The cumulative number of species captured from each consecutive segment was evaluated and analyzed with non-linear regression equations to estimate asymptotic species richness and the sampling distance that would attain 95% of this richness. The 95%-richness distance is a very conservative sampling length. The minimum sampling distance selected was 500 m because no significant difference was observed with species richness or percent metrics with the addition of distance. Since these river reaches do not typically possess riffle-run-pool habitat, reach structure increases species diversity by the presence of woody debris and scour pools.

For sampling, time duration ranged from 60–90 min, depending on stream complexity. The objective was to collect a representative sample of the fish assemblage using methods designed to collect all except very rare species and provide an unbiased measure of the proportional abundances of species.

During sampling, a single person positioned on the bow, used a dip net with 6 mm mesh (stretch) and attempted to capture all fish seen. This mesh size was effective in retaining small species and individuals such as minnows, darters, and topminnows. Captured fish were identified to species, counted, weighed in aggregate by species, and inspected for deformities, eroded fins, lesions, and tumor (DELT) anomalies (Sanders et al. 1999). Consistent with other IBI's, specimens less than 25 mm TL were considered young-of-year (Fausch et al. 1984; Karr et al. 1986), with the exception of some species that only attain these sizes, i.e., mosquitofish (*Gambusia affinis*). These young-of-year individuals were excluded from the analysis.

Data analyses.—Regional literature references were used to classify adult fish into taxonomic and ecological categories for computation of metrics (Appendix; Gerking 1945; Simon 1999b; Goldstein & Simon 1999). An analysis of variance (ANOVA) was used to test for sub-ecoregional differences in richness metrics, adjusted for catchment area. Finding no such differences, data from all ecoregions were aggregated. All of our impacted sites (n = 36) were classified into one of four categories according to the predominant type of human impact. Classification was done prior to sampling and was based on physical-chemical attributes related to hydrology and water and habitat quality. "Agricultural" sites were located in watershed with at least 50% of their surface area in intensive agriculture or less than 20% in urban land uses. "Point source" sites had been affected by major point source discharges of industrial or municipal waste (IDEM 2002). Since the 1990s, most major discharges into Indiana streams have been eliminated or have been heavily treated to reduce water quality impacts, and violations of water quality standards are much less common (IDEM 2002). Thus, the point source category largely represents a historical impact.

The least-impacted sites had relatively few impacts and represented the best remaining river segments in the ecoregions. These sites are not pristine, but generally had intact riparian corridors, minimal non-point source pollution, and limited point source pollution. We considered some agriculture impacts to represent background conditions at almost every site in Indiana.

Two datasets were used in developing the IBI. One set (n = 275) included representative, best-remaining, least-impacted sites and was used in the development group to identify appropriate metrics, devise metric scoring criteria, and construct the final IBI. Test data included 36 independent sites that were downstream of point source discharges that were used to validate the IBI and determine how well it reflected known patterns of human impacts.

Twenty-four candidate metrics were considered for inclusion in the Wabash River IBI (Table 1). These contained all of the relevant metrics used in previous warmwater stream IBIs, plus several additional metrics (Simon & Lyons 1995; Hughes & Oberdorff 1999). Prior to the analyses the metrics were transformed to better approximate normality (a $\log_e$ transformation for the number of individuals or biomass and an arcsine-square-root transformation for proportional metrics). Results of analyses were considered significant if $\alpha < 0.05$.

First, the variation in metric values was examined in relation to two natural factors, drainage area and geographic location, that might influence fish assemblages. Appropriate metrics would have either little variation relative to these two factors or a strong, monotonic, biologically meaningful relation that could be easily taken into account in IBI calculations (Hughes et al. 1998; Lyons et al. 2001). This analysis was limited to the 275 least-impacted samples from the development group to minimize the potential confounding effects of human impacts. Drainage area upstream of the sampling site ($\log_e$ transformed) was used as a measure of stream size. Data from large and great river reaches and preliminary analyses of a subset of our large-river reaches based on ecoregions (Eastern Corn Belt Plain ("north"); n = 83 and Interior River Lowland ("south"); n = 192) and sub-ecoregions in the Interior River Lowland (Woods et al. 1995) classified as "north" (Glaciated Wabash Lowlands sub-ecoregion; n = 110) and "south" (Wabash Bottomland sub-ecoregion; n = 82) did not show any substantial structural or compositional differences, so it was not necessary to derive separate reference condition expectations for either the two ecoregions nor the two sub-ecoregions in the final analyses. Regression analysis was used to evaluate patterns between each metric and drainage area, while an Analysis of Variance (ANOVA) for each metric was used to compare the "north" and "south" potential differences for ecoregion or sub-ecoregions. No statistically significant relationship was observed for drainage area, ecoregion, or sub-ecoregion.

Next, metric performance relative to a gradient of human impact was evaluated using the development samples. When examining the most- and least-degraded stream reaches, the assumption was that multiple-impact sites would have the most modified fish assemblages and least-impacted would have the least, with the intermediate impact classes somewhere in between. Metrics that fit this pattern, that is, that showed least-impacted sites as having the best values (highest or lowest depending on the specific metric) and multiple-impact sites having the worst values, were considered appropriate for our IBI. For each potential metric, an analysis of variance (ANOVA) was used with a Duncan multiple-range, multiple-comparison test (DMC) to assess differences among impact classes. If the metric value at the least-impacted sites were related to stream size, drainage area ($\log_e$ transformed) was included as a covariate in this analysis.

The final metrics chosen for inclusion in the IBI were based on their variation relative to natural factors, their relation to human impact, and whether they represented a unique aspect of the structure, composition, or functional organization of the fish assemblage (Hughes et al. 1998). Each final metric had an appropriate response pattern to both natural factors and human impacts. For those metrics that involved the same species and that were strongly correlated with each other (Pearson's $r >$ 0.6), a single representative metric was chosen for use in the index. The final metrics selected included at least one metric for each of the five attributes of fish assemblages that an IBI should include: species richness and composition, indicator species, trophic function, reproductive function, and individual abundance and condition (Simon & Lyons 1995).

Scoring criteria followed the classic 1, 3, and 5 scoring criteria established by Karr (1981) and Karr et al. (1986), which is consistent with previous adaptations of the IBI for other Indiana ecoregions (Simon 1991, 1994; Simon & Dufour 1998a, b) and large rivers (Simon 1992; Simon & Stahl 1998; Emery et al. 2003). A minimum possible score (0 points) was assigned when the metric value was below the level achieved by the development data set. For example, when a site did not possess a particular indicator species or guild, then the specific metric was assigned 0 points. The overall IBI

Table 1.—Candidate metrics considered for inclusion in a calibration of the index of biotic integrity (IBI) for the Wabash River. Species designations are provided in the appendix. The abbreviation wt stands for weight (biomass); n is the total number of fish captured. Metrics in bold are included in the final IBI.

Metric	Definition
CPUE	Catch of individuals per standard sampling distance (500-m).
CPUE2	Catch of individuals per standard sampling sistance, excluding individuals of tolerant species.
Total species	Total number of species collected.
Native species	Total species excluding exotic and non-indigenous species.
Number sucker species	Total number of species in the sucker family (Catostomidae).
Sunfish species	Number of species in the sunfish family (Centrarchidae), excluding black basses (genus *Micropterus*).
Centarchid species	Number of species in the sunfish family (Centrarchidae) including black basses (genus *Micropterus*).
Minnow species	Number of species in the minnow family (Cyprinidae).
Darter species	Number of species in the perch family (Percidae) in the genera *Ammocrypta, Etheostoma, Crystallaria*, and *Percina*.
Sensitive species	Number of species sensitive to anthropogenic disturbance of physical and chemical integrity.
% DELT (n)	Percentage of total fish captured that upon gross inspection possessed deformities, eroded fins, lesions, or tumors.
% Top carnivores (n)	Percentage of total fish captured that were top carnivores.
% Insectivores (n)	Percentage of total fish captured that were insectivores.
% Detritivores (n)	Percentage of total fish captured that were detritivores.
% Omnivores (n)	Percentage of total fish captured that were omnivores; i.e., consumed at least 25% animal and 25% plant material.
% Great River (n)	Percentage of total fish captured that were obligate great-river species.
% Large-river species (n)	Percentage of total fish captured that were obligate large-river species.
% Lithophil (n)	Percentage of total fish captured that were simple lithophilic spawners (i.e., first spawned on clean rocky surface without preparing a nest or guarding their eggs).
% Round-bodied suckers (n)	Percentage of total fish captured in the genera *Cycleptus* (blue sucker), *Hypentelium* (hog sucker), *Minytrema* (spotted sucker), *Erimyzon* (chubsuckers), and *Moxostoma* (redhorses).
% Tolerant (n)	Percentage of total fish captured that were considered tolerant of environmental degradation.
% Top carnivore (wt)	Percentage of total biomass accounted for by top carnivores.
% Insectivores (wt)	Percentage of total biomass captured that were insectivores.
% Detritivores (wt)	Percentage of total biomass captured that were detritivores.
% Omnivores (wt)	Percentage of total biomas captured that were omnivores; i.e., consumed at least 25% animal and 25% plant material.

score was the sum of 12 metric scores and ranged between 0 and 60.

The IBI was validated with data from the test group by performing an ANOVA and a DMC on the 36 test samples, with impact categories as the main effect and IBI score as the response variable. Index of biotic integrity scores were converted to a proportion from 0 to 1 and then arcsine-square-root transformed prior to analysis. The IBI was considered valid if there were significant differences among impact categories, with the least-impacted samples having the highest scores and the point source samples the lowest.

RESULTS

Fish assemblages were sampled at 275 Indiana sites in the Wabash River between

1993–2001 (Fig. 1). An independent test sample set of 36 sites exposed to human-impacted conditions were collected between 2002–2005 to evaluate the final IBI. Of the 275 least-impacted sites, 31 were classified as non-impacted, 231 as agriculture exposed, and 13 as point source pollution impacted. Eighty-three sites were in the northern ECBP, while 110 sites were in the northern portion of the IRL ecoregion, and the remaining 82 sites were located in the southern portion of the IRL ecoregion. Watershed areas ranged from 1139.6 (440 mi^2) to 85,231.7 km^2 (32,908 mi^2).

A total of 119 fish species was collected (Appendix) including 57,519 individuals and 19,825 kg of biomass. The study reaches had a wide variety of fish assemblages. Individual samples yielded from 2–47 species, from 23–5437 individuals (minus schooling species), and from 2.14–34.71 kg of biomass. The most frequently encountered species were carp (92% of samples), channel catfish (84%), gizzard shad (82%), and freshwater drum (77%). The most numerous species were spotfin shiner (12,878 individuals), emerald shiner (9959 individuals), gizzard shad (5296 individuals), and river shiner (4366 individuals), and the greatest biomass was for carp (1057.3 kg), freshwater drum (201.7 kg), and channel catfish (160.5 kg).

Index development.—Of the 24 potential metrics considered (see Table 1 for designations and definitions), none varied significantly in relation to either river size or geographic (ecoregion or sub-ecoregion) location for our 31 least-impacted development group samples. This is most likely due to large and great rivers being an assimilator of upstream conditions. Large and great rivers most likely are already beyond the inflexion or accretion curve that is so dramatic in headwater and wadeable streams and thus would not demonstrate the pronounced drainage area relationships seen in small systems. These results are consistent with other large and great river calibrations (Simon & Emery 1998; Niemela et al. 1999; Emery et al. 2003). In addition, the River Continuum Concept (RCC) suggests increasing species richness with downstream drainage area increase; however, it is important to note that the Wabash River main stem is the trunk of the RCC since the increase in species richness occurs in the tributaries. Only a single metric, % great river species, had a positive but weak correlation with stream size ($P = 0.036$). None of the metrics had values that differed between drainage area, or northern and southern ecoregions or between or northern and southern sub-ecoregions.

Twenty metrics met the criteria for inclusion in the IBI based on an analysis of all 275 development group samples. Four of these metrics were excluded because of redundancy. The metrics total species and native species provided almost identical results ($r = 0.924$) and differed by more than one species at only one site. The number of native species metric was retained, and the total number of species metric was dropped. The metrics % omnivore ($r = 0.893$), % tolerant ($r = 0.888$), and % detritivore ($r = 0.872$), had similar patterns across the impact classes regardless of whether calculated based on the number of individuals or the biomass collected. Since biomass was used as a separate indicator, the % omnivore and % tolerant species metrics was retained.

One metric, % DELT was retained that did not meet the criteria for inclusion. This metric has been shown to be particularly sensitive to industrial and toxic discharges in numerous other studies (Sanders et al. 1999). In this data set, the DELT percentages were consistently low and did not differ among impact categories; but since sites with major untreated point source discharges were difficult to find during the time of our sampling, this was not considered a problem. However, such pollution types were common in this ecoregion as recent as the 1970s, so the DELT metric was retained to provide sensitivity to potential impacts that were not encompassed within the dataset.

Scoring criteria for the final twelve metrics are provided in Fig. 2 and Table 2. Different criteria were not needed for northern and southern portions of the ecoregion; nor were different metric calibrations needed for stream sizes including % large-river species (< 5,957 km^2) and % great-river species (> 5,957 km^2). The overall IBI score was the sum of the individual scores for the 12 metrics and could range from 0 (worst) to 60 (best).

Index validation.—Overall IBI scores for 36 test group samples ranged from 16 (very poor) to 31 (fair) (Fig. 3), while the entire 275 combined set of development and test samples ranged from 12 (very poor) to 45 (fair-good) (Fig. 4). The least-impacted category was significantly greater than the agriculture and non-

Table 2.—Final metrics and scoring criteria for the Wabash River, Indiana.

		Scoring criteria and rating (points)		
Metric	Location	Poor (1)	Fair (3)	Good (5)
Native species (Total)	All	<10	10–20	>20
Centrarchid species	All	≤2	3–4	≥5
Round-bodied sucker	All	<2	2–4	≥5
Sensitive species	All	≤3	4–7	≥8
% Tolerant	All	<71.6%	43.3–71.6%	>43.3%
% Omnivores	All	<68.3%	36.7–68.3%	>36.7%
% Insectivores	All	<25.0%	25.0–50.0%	>50.0%
% Carnivores	All	<10% or >40%	10–20% & 30–40%	>20–30%
% Large-river species	All	<28.3%	28.3–56.6%	>56.6%
CPUE	All	<600	600–1200	>1200
% Lithophils	All	<15%	15–30%	>30%
% DELT	All	>1.3%	0.1–1.3%	<0.1%

point source categories, which did not differ from each other. Least-impacted samples (*n* = 31) had a mean of 34 (fair) and a range of 22–45 compared to agriculture samples (*n* = 231), which had a mean of 24 (poor) and a range of 13–44, and a mean of 22 (very poor) and a range of 16–29 for point source samples. Ninety percent of the least-impacted samples were rated between poor and fair, and 83% of the impact samples were rated as poor or very poor.

Variation within years.—Substantial annual variation in IBI scores among samples occurred at some sites but not at others. Generally, variation was lowest at the least-impacted sites and highest at the point-source impact sites. Within-year variation in IBI scores for sites ranged from 0 to 8 points with a mean of 3.2 points, and among- year variation ranged from 0 to 12 points with a mean of 4.1 points. All of these sites remained within the same integrity class. One site had ratings that ranged from very poor to fair between years. A single point-source pollution site varied 12 points and fluctuated in rating from very poor to poor between years.

DISCUSSION

Metric selection.—A wide range of metrics representative of the structure, composition, and functional organization of the Wabash River in the Interior River Lowland and Eastern Corn Belt Plain was considered. Most of the selected metrics have been found useful in other stream IBI applications, though they were modified to reflect understanding of river assemblages in this area. For example, previous stream versions of IBI have not used a "0" score when a metric attribute is not present. This simple adjustment in the scoring procedure reduced inherent natural variation in the degraded sites. Simon et al. (1998) used this procedure in vernal ponds when evaluating a multi-species assemblage and coastal wetlands in Lake Michigan (Simon & Stewart 2006).

The choice of metrics reflected a balance between different types of metrics (i.e., structure and function) and different measures of assemblage characteristics (i.e., composition, tolerance, trophic guild, reproductive guild, abundance, and condition). As recommended by Simon & Lyons (1995) and Karr & Chu (1999), metrics that related to species richness and composition (number of native, minnow, sucker, and sunfish species), indicator species (sensitive species, % tolerant species, % pioneer species), trophic function (% insectivores, % detritivores, % carnivores), reproductive function (% lithophils), abundance (CPUE), and fish condition (% DELT). Some previous IBIs have used biomass to assess biological integrity when there are large differences in adult size among species or when species richness is low (Hughes & Gammon 1987; Goldstein et al. 1994; Minns et al. 1994; Niemela et al. 1999; Lyons et al. 2000; Emery et al. 2003). Percent metrics were based entirely on individuals since this biomass data are used for another indicator other than the IBI, i.e., index of well being (Gammon 1976).

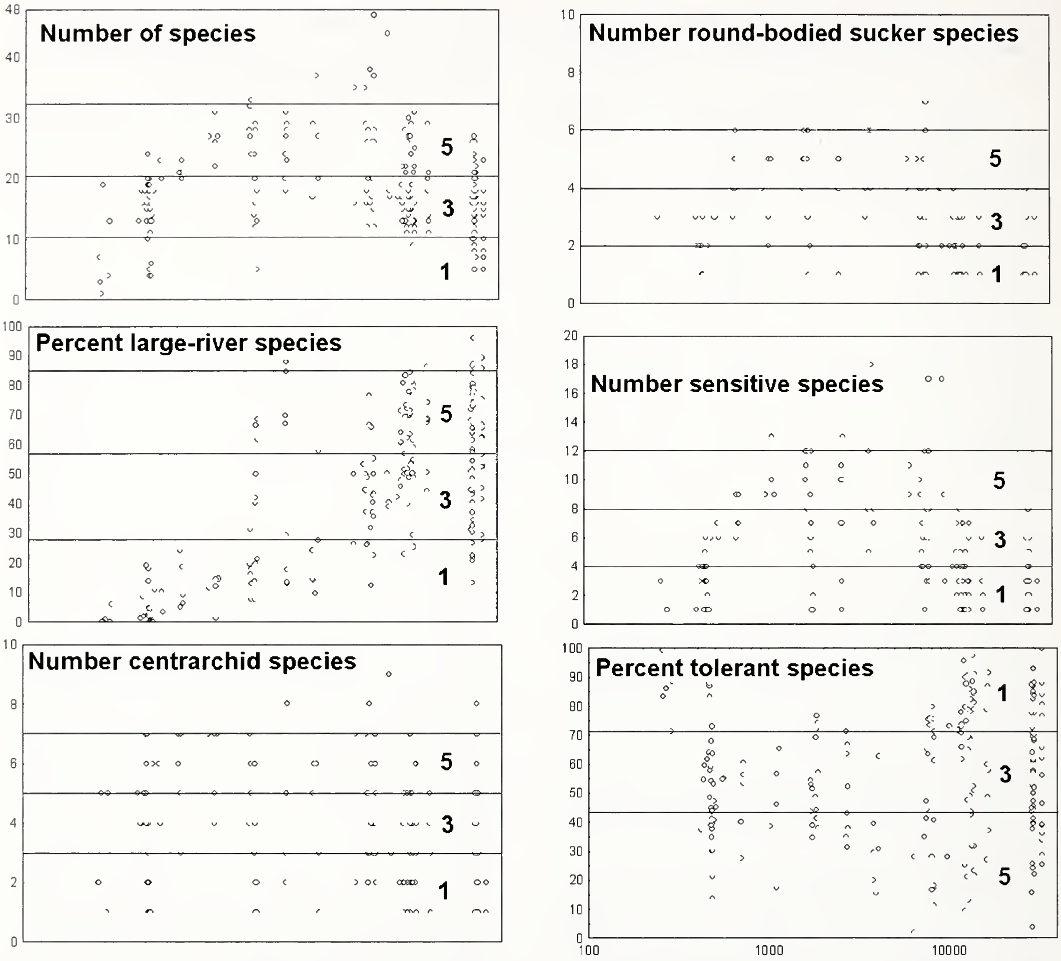

Figure 2.—Index of Biotic Integrity (IBI) metric scoring criteria for the Wabash River.

The IBI is an important component of an assessment toolbox that can be used by fisheries and environmental professionals.

Only a single metric included in the final metrics of the calibration related weakly to river size, as measured by drainage area. This is consistent with the results of other large-river IBIs (Simon 1992; Simon 1994; Simon & Dufour 1998a, b; Simon & Emery 1995; Emery et al. 2003), and Ohio (Ohio EPA 1989) calibrations, which did not show any positive correlation with species richness metrics.

Validation and variation.—An analysis of the test dataset validated the effectiveness of the Wabash River IBI (Fig. 3). As is necessary for an effective index, the sites were judged based on *a priori*, independent (i.e., non-fish) criteria: our least impacted sites had the highest IBI scores, and sites that we judged worst—the point-source sites—had the lowest scores. Based on the entire developmental dataset, the same patterns were observed with agricultural sites attained an intermediate level of impact with associated intermediate scores (Fig. 4). Because the test data were not used in any phase of the index development, these results are strong evidence that the IBI accurately measures the condition of large and great rivers (Karr & Chu 1999; Simon 1999a). These results support the utility of an IBI based on a subset of the river fish community for rapid biological assessment.

Although our new IBI appears to provide an accurate measure of stream ecosystem condition, this measure is not particularly precise, especially between years. This may be due to

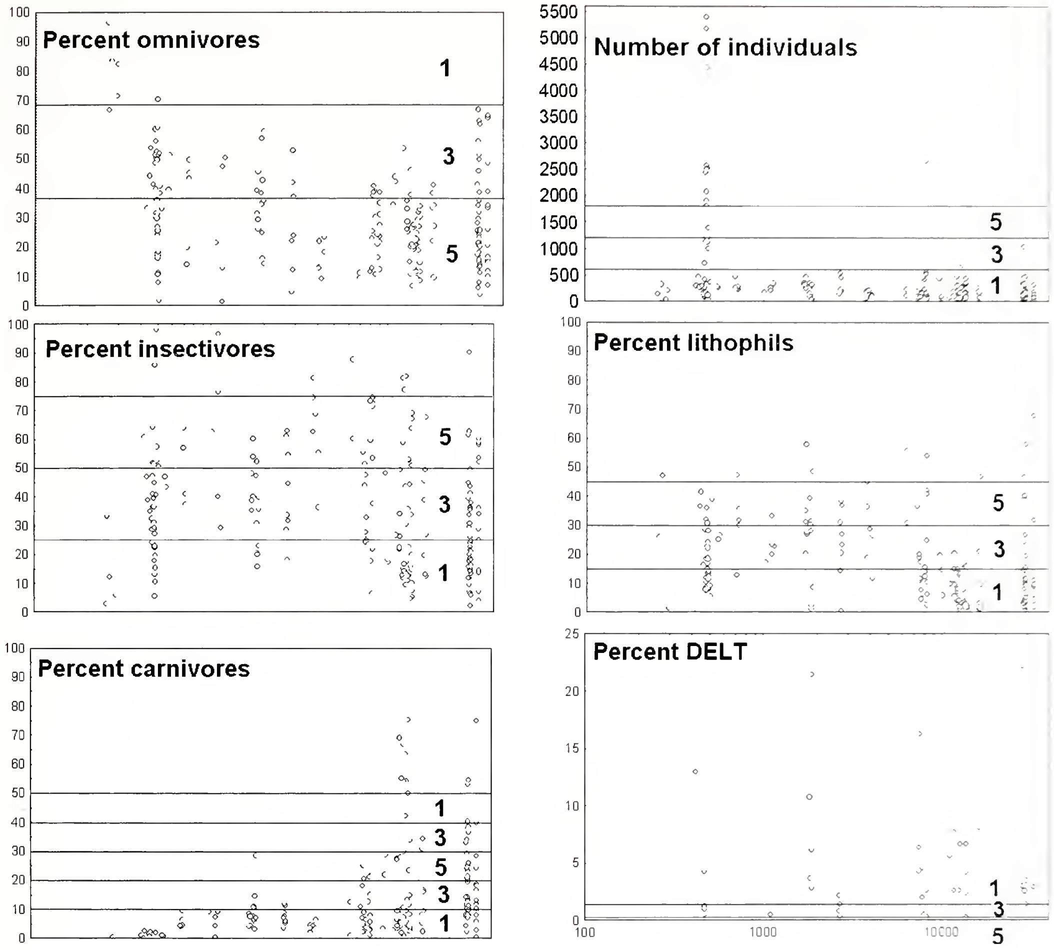

Figure 2.—Continued.

extremes in hydrologic conditions between years; however, at the highest quality river reaches little variability was observed. The temporal variation within high-quality reaches was relatively low, at 0–5 points, or about 0–8.3% of actual IBI scores, but much higher within degraded reaches, at 4–12 points or 6.7–20% of actual scores. Several other studies from midwestern United States streams have also found greater variation over time in IBI scores at degraded sites, although variation has typically been in the range of 25–60% of actual scores (summarized in Fore et al. 1994; Yoder & Rankin 1995; Gammon & Simon 2000). These findings suggest that strong temporal variation in fish assemblage characteristics is a real phenomena at degraded sites and not an artifact of the particular IBI used. Variation in IBI scores may be a signal of degradation (Karr & Chu 1999). Additional studies are needed to document the status and trends in biotic integrity at sites with human impacts than will be needed at least-impacted sites. Additional sampling is recommended from different periods to assess the condition of a site of unknown quality. Gammon & Simon (2000) found that four metrics (i.e., total number of species, number of centrarchid species, number of sensitive species, and % lithophils) responded at sites across the Eastern Corn Belt Plain ecoregion and a portion of the Interior River Lowland ecoregion; however, this was not anticipated to be an observed relationship for reference condition calibration since no single site is expected to represent the highest integrity for all

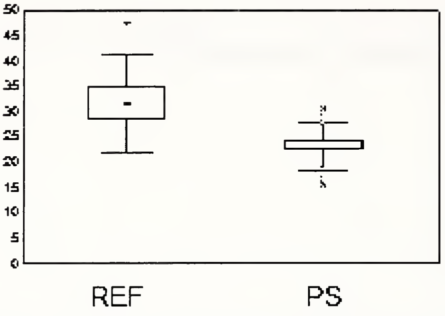

Figure 3.—Mean IBI scores and 95% confidence intervals for reference IBI categories and 36 test samples for point source discharge. Abbreviations are as follows: REF = reference condition, and PS = point source.

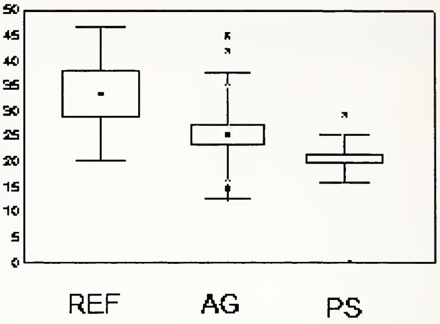

Figure 4.—Distribution of IBI scores among ratings for impact categories for all 275 developmental samples. Abbreviations are as follows: REF = reference condition, AG = agriculture, and PS = point source.

metrics. Thus, individual metrics may show a trend in scores across ecoregions without metric expectations showing similar trends since the upper line is derived by either the maximum observed line for percentage metrics or 95 percentile for species structural and compositional metrics.

Application.—Since no statistically significant difference was observed in metric response for drainage area, ecoregion, or sub-ecoregion expectations for the reference condition, a single IBI was calibrated for the Wabash River. All studies of large and great rivers have not shown a relationship with drainage area (Goldstein et al. 1994; Minns et al. 1994; Niemela et al. 1999; Lyons et al. 2000; Emery et al. 2003; Simon & Stewart 2006), or across ecoregion or sub-ecoregion (Goldstein et al. 1994; Minns et al. 1994; Niemela et al. 1999; Lyons et al. 2000; Emery et al. 2003). Thus, a relationship between drainage area, ecoregion, or sub-ecoregion and metric expectations was not expected in this study. Simon & Stahl (1998) and Simon (1992) did not observe a relationship between fish assemblages and ecoregions or sub-ecoregions for the Eastern Corn Belt Plain, Interior River Lowland, and Interior River Plateau. Although a drainage area relationship is usually seen with increasing species accretion in headwater and wadeable streams, the RCC predicts that large and great rivers should not show increasing expectations. Once species diversity accretion is attained in large rivers, the replacement of small headwater species with large-river species does not increase substantially since the drainage area is already at the maximum for the watershed.

The least-impacted sites had higher IBI scores and better ecosystem quality than sites that are more strongly impacted by human activities. Most least-impacted samples were rated as fair, and seldom were sites rated as good. On the contrary, many impacted sites were rated as poor. The sites rated as poor were representative of widescale land use changes that affected entire river reaches, but would not have been apparent from the local riparian and instream condition. Regional estimates of stream conditions showed that 42% of the stream reaches in the Interior River Lowland ecoregion had fish assemblages in poor or fair ecological condition, while large-river reaches in the Eastern Corn Belt Plain ecoregion had 36% fair and 23% good. Much of Indiana is in agricultural land use and serves as a background condition, thus sediment and nutrient runoff from upstream agriculture may well have reduced ecosystem quality below least-impacted site conditions on other large rivers. Despite the inclusion of lower quality sites in the developmental data base for the IBI, the classification of these sites indicated that both the metrics and the final IBI classification accurately portrayed the actual stream condition.

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LITERATURE CITED

Davis, W.S. & T.P. Simon. 1988. Sampling and data evaluation requirements for fish and macroinvertebrate communities. Pp. 89–97, *In* Proceedings of the First National Workshop on Biocriteria, Lincolnwood, Illinois. (T.P. Simon, L.L. Holst & L.J. Shepard, eds.). EPA 905/9-89/003. USEPA, Region V, Instream Biocriteria and Ecological Assessments Committee, Chicago, Illinois.

Emery, E.B., T.P. Simon, F.H. McCormick, P.L. Angermeier, J.E. DeShon, C.O. Yoder, R.E. Sanders, W.D. Pearson, G.D. Hickman, R.J. Reash & J.A. Thomas. 2003. Development of a multimetric index for assessing the biological condition of the Ohio River. Transactions of the American Fisheries Society 132:791–808.

Fausch, K.D., J.R. Karr & P.R. Yant. 1984. Regional application of an index of biotic integrity based on stream fish communities. Transactions of the American Fisheries Society 113:39–55.

Fausch, K.D., J. Lyons, J.R. Karr & P.L. Angermeier. 1990. Fish communities as indicators of environmental degradation. Pp. 123–144, *In* Biological indicators of stress in fish. (S.M. Adams, ed.). American Fisheries Society, Symposium 8, Bethesda, Maryland.

Gammon, J.R. & T.P. Simon. 2000. Variation in a great river index of biotic integrity over a 20 year period. Hydrobiologia 422/423:291–304.

Goldstein, R.M. & T.P. Simon. 1999. Towards a united definition of guild structure for feeding ecology of North American freshwater fishes. Pp. 123–202, *In* Assessing the Sustainability and Biological Integrity of Water Resources Using Fish Communities. (T.P. Simon, ed.). CRC Press. Boca Raton, Florida.

Goldstein, R.M., T.P. Simon, P.A. Bailey, M. Ell, E. Pearson, K. Schmidt & J.W. Emblom. 1994. Concepts for an index of biotic integrity for streams of the Red River of the North Basin. Pp. 169–180, *In* Proceedings of the North Dakota Water Quality Symposium. March 30–31, 1994, Fargo, North Dakota.

Hughes, R.M. & J.R. Gammon. 1987. Longitudinal changes in fish assemblages and water quality in the Willamette River, Oregon. Transactions of the American Fisheries Society 116:196–209.

Hughes, R.M. & T. Oberdorff. 1999. Applications of IBI concepts and metrics to waters outside the United States and Canada. Pp. 79–93. *In* Assessing the Sustainability and Biological Integrity of Water Resources Using Fish Communities. (T.P. Simon, ed.). CRC Press. Boca Raton, Florida.

Hughes, R.M., P.R. Kaufmann, A.T. Herlihy, T.M. Kincaid, L. Reynolds & D.P. Larsen. 1998. A process for developing and evaluating indices of fish assemblage integrity. Canadian Journal of Fisheries and Aquatic Sciences 55:1618–1631.

Indiana Department of Environmental Management (IDEM). 2002. 305(b) report to Congress. IDEM, Indianapolis, Indiana.

Karr, J.R. 1981. Assessment of biotic integrity using fish communities. Fisheries 6:21–27.

Karr, J.R. & E.W. Chu. 1999. Restoring life in running waters: Better biological monitoring. Island Press. Covelo, California.

Karr, J.R., K.D. Fausch, P.L. Angermeier, P.R. Yant & I.J. Schlosser. 1986. Assessing biological integrity in running waters: A method and its rationale. Illinois Natural History Survey Special Publication 5. Champaign, Illinois.

Lyons, J., L. Wang & T.D. Simonson. 1996. Development and validation of an index of biotic integrity for coldwater streams in Wisconsin. North American Journal of Fisheries Management 16:241–256.

Lyons, J., A. Gutiérrez-Hernández, E. Díaz-Pardo, E. Soto-Galera, M. Medina-Nava & R. Pineda-López. 2000. Development of a preliminary index of biotic integrity (IBI) based on fish assemblages to assess ecosystem condition in the lakes of central Mexico. Hydrobiolgia 418:57–72.

Lyons, J., R.R. Piette & K.W. Niermeyer. 2001. Development, validation, and application of a fish-based index of biotic integrity for Wisconsin's large warmwater rivers. Transactions of the American Fisheries Society 130:1077–1094.

Minns, C.K., V.C. Cairns, R.G. Randall & J.E. Moore. 1994. An index of biotic integrity (IBI) for fish assemblages in the littoral zone of Great Lakes' areas of concern. Canadian Journal of Fisheries and Aquatic Sciences 51:1804–1822.

Mundahl, N.D. & T.P. Simon. 1999. Development and application of an index of biotic integrity for coldwater streams of the upper Midwestern United States. Pp. 383–416, *In* Assessing the Sustainability and Biological Integrity of Water Resources Using Fish Communities. (T.P. Simon, ed.). CRC Press. Boca Raton, Florida.

Niemela, S., E. Pearson, T.P. Simon, R.M. Goldstein & P.A. Bailey. 1999. Development of an index of biotic integrity for the species depauperate Lake Agassiz Plain Ecoregion, North Dakota and Minnesota. Pp. 339–380, *In* Assessing the Sustainability and Biological Integrity of Water Rresources Using Fish Communities. (T.P. Simon, ed.). CRC Press. Boca Raton, Florida.

Omernik, J.M. & A.L. Gallant. 1988. Ecoregions of the upper Midwest States. EPA/600/3-88/037. U.S. Environmental Protection Agency. Corvallis, Oregon.

Sanders, R.E., R.J. Miltner, C.O. Yoder & E.T. Rankin. 1999. The use of external deformities, erosion, lesions, and tumors (DELT anomalies) in fish assemblages for characterizing aquatic resources: A case study of seven Ohio streams. Pp. 225–246, *In* Assessing the Sustainability and Biological Integrity of Water Resources Using Fish Communities. (T.P. Simon, ed.). CRC Press. Boca Raton, Florida.

Simon, T.P. 1991. Development of index of biotic integrity expectations for the ecoregions of Indiana. I. Central Corn Belt Plain. EPA 905-9-91-025. U. S. Environmental Protection Agency, Chicago, Illinois.

Simon, T.P. 1992. Development of biological criteria for large rivers with an emphasis on an assessment of the White River drainage, Indiana. EPA 905-R-92-026. U.S. Environmental Protection Agency. Chicago, Illinois.

Simon, T.P. 1994. Development of index of biotic integrity expectations for the ecoregions of Indiana. II. Huron-Erie Lake Plain. EPA 905-R-92-027. U.S. Environmental Protection Agency, Chicago, Illinois.

Simon, T.P. (ed.). 1999a. Assessing the Sustainability and Biological Integrity of Water Resources Using Fish Communities. CRC Press. Boca Raton, Florida.

Simon, T.P. 1999b. Assessment of Balon's reproductive guilds with application to midwestern North American freshwater fishes. Pp. 97–121, *In* Assessing the Sustainability and Biological Integrity of Water Resources Using Fish Communities. (T.P. Simon, ed.). CRC Press. Boca Raton, Florida.

Simon, T. P. 2001. The use of biological criteria as a tool for water resource management. Environmental Science and Policy 3:S43–S49.

Simon, T.P. 2002a. Biological response signatures: Patterns in aquatic assemblages. CRC Press. Boca Raton, Florida.

Simon, T.P. & R.L. Dufour. 1998a. Development of index of biotic integrity expectations for the ecoregions of Indiana. V. Eastern Corn Belt Plain. EPA 905-R-96-003. U.S. Environmental Protection Agency. Chicago, Illinois.

Simon, T.P. & R.L. Dufour. 1998b. Development of index of biotic integrity expectations for the ecoregions of Indiana. IV. Northern Indiana Till Plain. EPA 905-R-96-002. U.S. Environmental Protection Agency, Chicago, Illinois.

Simon, T.P. & E.B. Emery. 1995. Modification and assessment of an Index of Biotic Integrity to quantify water resource quality in great rivers. Regulated Rivers: Research and Management 11: 283–298.

Simon, T.P. & J. Lyons. 1995. Application of the index of biotic integrity to evaluate water resources integrity in freshwater ecosystems. Pp. 245–262, *In* Biological Assessment and Criteria: Tools for Water Resource Planning and Decision Making. (W.S. Davis & T.P. Simon, eds.). Lewis Press, Boca Raton, Florida.

Simon, T.P., E.T. Rankin, R.L. Dufour & S.A. Newhouse. 2003. Using biological criteria for establishing restoration and ecological recovery endpoints. Pp. 81–94, *In* Biological Response Dignatures: Indicator Patterns Using Aquatic Communities. (T.P. Simon, ed.). CRC Press. Boca Raton, Florida.

Simon, T.P. & R.E. Sanders. 1999. Applying an index of biotic integrity based on Great-River fish communities: Considerations in sampling and interpretation. Pp. 475–505, *In* Assessing the Sustainability and Biological Integrity of Water Resources Using Fish Communities. (T.P. Simon, ed.). CRC Press. Boca Raton, Florida.

Simon, T.P. & J.R. Stahl. 1998. Development of index of biotic integrity expectations for the Wabash River. EPA 905-R-96-005. U.S. Environmental Protection Agency, Chicago, Illinois.

Simon, T.P. & J.R. Stahl. 2001. Clarifying statement for the report entitled: "Index of Biotic Integrity Expectations for the Wabash River." U.S. Environmental Protection Agency, Region 5, Chicago, Illinois.

Simon, T.P. & P.M. Stewart (eds.). 2006. Coastal Wetlands of the Laurentian Great Lakes: Health, Habitat and Indicators. Authorhouse Press. Bloomington, Indiana.

Strahler, A.N. 1957. Quantitative analysis of watershed geomorphology. Transactions of the American Geophysical Union 38:913–920.

Woods, A.J., J.M. Omernik, S.C. Brockman, T.D. Gerber, W.D. Hosteter, S.H. Azevedo, T.P. Simon, C.O. Yoder, P. Merchant, T.R. Loveland, C.L. Bridges, G.L. Overmier, K. Capuzzi, S.A. Newhouse, T. Nash, J.R. Gammon, B.K. Andreas & J. Harrington. 1995. Ecoregions of Indiana and Ohio. Map. U.S. Environmental Protection Agency, Corvallis, Oregon.

Yoder, C.O. & E.T. Rankin. 1995. Biological criteria program development and implementation in Ohio. Pp. 109–144, *In* Biological Assessment and Criteria: Tools for Water Resource Planning and Decision Making. (T.P. Simon, ed.) Lewis Press. Boca Raton, Florida.

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Appendix.—Classification of fishes captured during this study. For feeding, P = parasite, F = filter, C = "carnivore" indicates the top carnivore, I = insectivore, H = herbivore, and O = omnivore. For habitat, "large" indicates streams greater than 2,590 but less than 5,957 square kilometer drainage area. For spawning, SL = simple lithophil. "Other" indicates that the species was not included within one of the categories used in calculating particular metrics. Species are listed in taxonomic order by family and alphabetically within family by scientific name. Classifications were taken from Simon (1999b), Goldstein & Simon (1999), and unpublished data.

Common name	Scientific name	Origin	Tolerance	Feeding	Habitat	Spawning
Lamprey	Petromyzontidae					
Chestnut lamprey	*Ichthyomyzon castenaus*	Native	Other	P	Large	Other
Silver lamprey	*Ichthyomyzon unicuspis*	Native	Other	P	Large	Other
American brook lamprey	*Lampetra appendix*	Native	Intolerant	F	Other	Other
Least brook lamprey	*Lampetra aepyptera*	Native	Intolerant	F	Other	Other
Gar	Lepisosteidae					
Spotted gar	*Lepisosteus oculatus*	Native	Other	C	Other	Other
Longnose gar	*Lepisosteus osseus*	Native	Other	C	Other	Other
Shortnose gar	*Lepisosteus platostomus*	Native	Other	C	Large	Other
Sturgeon	Acipenseridae					
Lake sturgeon	*Acipenser fulvescens*	Native	Other	I	Large	SL
Shovelnose sturgeon	*Scaphirhynchus platorhynchus*	Native	Other	I	Large	SL
Paddlefish	Polyodontidae					
Paddlefish	*Polyodon spathula*	Native	Intolerant	P	Large	SL
Bowfin	Amiidae					
Bowfin	*Amia calva*	Native	Other	C	Other	Other
Herring	Clupeidae					
Skipjack herring	*Alosa chrysochloris*	Native	Other	C	Large	Other
Gizzard shad	*Dorosoma cepedianum*	Native	Other	O	Other	Other
Threadfin shad	*Dorosoma petenense*	Native	Other	O	Large	Other
Mooneye	Hiodontidae					
Goldeye	*Hiodon alsoides*	Native	Intolerant	I	Large	Other
Mooneye	*Hiodon tergisus*	Native	Intolerant	I	Large	Other
Minnow	Cyprinidae					
Stoneroller minnow	*Campostoma anomalum*	Native	Other	H	Other	Other
Goldfish	*Carassius auratus*	Exotic	Tolerant	O	Other	Other
Spotfin shiner	*Cyprinella spiloptera*	Native	Other	I	Other	Other
Steelcolor shiner	*Cyprinella whipplei*	Native	Other	I	Other	Other
Common carp	*Cyprinus carpio*	Exotic	Tolerant	O	Other	Other
Grass carp	*Ctenopharyngodon idella*	Exotic	Tolerant	O	Other	Other
Silverjaw shiner	*Ericymba buccata*	Native	Other	I	Other	Other
Streamline chub	*Erimystax dissimilis*	Native	Intolerant	I	Large	SL
Gravel chub	*Erimystax x-punctata*	Native	Intolerant	I	Large	SL
Bigeye chub	*Hybopsis amblops*	Native	Intolerant	I	Other	SL
Mississippi silvery minnow	*Hybognathus nuchalis*	Native	Other	O	Large	SL

Appendix.—Continued.

Common name	Scientific name	Origin	Tolerance	Feeding	Habitat	Spawning
Silver carp	*Hypopthalmichthys molitrix*	Exotic	Tolerant	H	Large	Other
Bighead carp	*Hypophthalmichthys nobilis*	Exotic	Tolerant	I	Other	Other
Striped shiner	*Luxilus chrysocephalus*	Native	Other		Other	Other
					Other	
Ribbon shiner	*Lythrurus fumeus*	Native	Other	I	Other	Other
Redfin shiner	*Lythrurus umbratilis*	Native	Other	I	Other	Other
Shoal chub	*Macrhybopsis hyostoma*	Native	Other	I	Large	Other
Silver chub	*Macrhybopsis storeriana*	Native	Other	I	Large	Other
Hornyhead chub	*Nocomis biguttatus*	Native	Intolerant	I	Other	Other
River chub	*Nocomis micropogon*	Native	Intolerant	I	Large	Other
Golden shiner	*Notemigonus crysoleucas*	Native	Tolerant	I	Other	Other
Emerald shiner	*Notropis atherinoides*	Native	Other	I	Large	Other
River shiner	*Notropis blennius*	Native	Other	I	Large	SL
Bigeye shiner	*Notropis boops*	Native	Intolerant	I	Other	SL
Ghost shiner	*Notropis buchanani*	Native	Other	I	Other	Other
Spottail shiner	*Notropis hudsonius*	Native	Other	I	Large	Other
Silver shiner	*Notropis photogenis*	Native	Intolerant	I	Other	SL
Rosyface shiner	*Notropis rubellus*	Native	Intolerant	I	Other	SL
Silverband shiner	*Notropis shumardi*	Native	Intolerant	I	Large	SL
Sand shiner	*Notropis stramineus*	Native	Other	I	Other	Other
Mimic shiner	*Notropis volucellus*	Native	Intolerant	I	Large	Other
Channel shiner	*Notropis wickliffi*	Native	Other	I	Large	Other
Suckermouth minnow	*Phenacobius mirabilis*	Native	Other	I	Other	SL
Bluntnose minnow	*Pimephales notatus*	Native	Tolerant	O	Other	Other
Fathead minnow	*Pimephales promelas*	Native	Tolerant	O	Other	Other
Bullhead minnow	*Pimephales vigilax*	Native	Other	I	Large	Other
Western blacknose dace	*Rhinichthys obtusus*	Native	Tolerant	—	Other	SL
Creek chub	*Semotilus atromaculatus*	Native	Tolerant	—	Other	Other
Sucker	Catostomidae					
River carpsucker	*Carpiodes carpio*	Native	Other	O	Other	Other
Quillback	*Carpiodes cyprinus*	Native	Other	O	Other	Other
Highfin carpsucker	*Carpiodes velifer*	Native	Intolerant	O	Other	Other
White sucker	*Catostomus commersonii*	Native	Tolerant	O	Other	SL
Blue sucker	*Cycleptus elongatus*	Native	Intolerant	I	Large	SL
Lake chubsucker	*Erimyzon sucetta*	Native	Other	I	Other	Other
Northern hogsucker	*Hypentelium nigricans*	Native	Intolerant	I	Other	SL
Smallmouth buffalo	*Ictiobus bubalus*	Native	Other	O	Large	Other
Bigmouth buffalo	*Ictiobus cyprinellus*	Native	Other	O	Large	Other
Black buffalo	*Ictiobus niger*	Native	Other	O	Large	Other
Spotted sucker	*Minytrema melanops*	Native	Other	I	Other	SL
Silver redhorse	*Moxostoma anisurum*	Native	Intolerant	I	Other	SL
River redhorse	*Moxostoma carinatum*	Native	Intolerant	I	Other	SL
Black redhorse	*Moxostoma duquesnei*	Native	Intolerant	I	Other	SL
Golden redhorse	*Moxostoma erythrurum*	Native	Intolerant	I	Other	SL
Shorthead redhorse	*Moxostoma macrolepidotum*	Native	Intolerant	I	Other	SL

Appendix.—Continued.

Common name	Scientific name	Origin	Tolerance	Feeding	Habitat	Spawning
Bullhead catfish	Ictaluridae					
Yellow bullhead	*Ameiurus natalis*	Native	Other	I	Other	Other
Black bullhead	*Ameiurus melas*	Native	Tolerant	I	Other	Other
Brown bullhead	*Ameiurus nebulosus*	Native	Other	I	Other	Other
Channel catfish	*Ictalurus punctatus*	Native	Other	C	Large	Other
Blue catfish	*ictalurus furcatus*	Native	Other	C	Large	Other
Mountain madtom	*Noturus eleutherus*	Native	Intolerant	I	Other	Other
Stonecat	*Noturus flavus*	Native	Intolerant	I	Other	Other
Brindled madtom	*Noturus miurus*	Native	Intolerant	I	Other	Other
Freckled madtom	*Noturus nocturnus*	Native	Intolerant	I	Other	Other
Flathead catfish	*Pylodictis olivaris*	Native	Other	C	Large	Other
Pike	Esocidae					
Grass pickerel	*Esox americanus*	Native	Other	C	Other	Other
Mudminnow	Umbridae					
Central mudminnow	*Umbra limi*	Native	Tolerant	O	Other	Other
Topminnow	Fundulidae					
Blackstripe topminnow	*Fundulus notatus*	Native	Other	I	Other	Other
Livebearer	Peciliidae					
Mosquitofish	*Gambusia affinis*	Native	Other	I	Other	Other
Silverside	Atherinidae					
Brook silverside	*Labidesthes sicculus*	Native	Other	I	Other	Other
Pirate perch	Aphredoderidae					
Pirate perch	*Apheredoderus sayanus*	Native	Other	I	Other	Other
Sculpin	Cottidae					
Mottled sculpin	*Cottus bairdi*	Native	Other	I	Other	Other
Banded sculpin	*Cottus carolinae*	Native	Other	I	Other	Other
Temperate bass	Moronidae					
White bass	*Morone chrysops*	Native	Other	C	Large	Other
Yellow bass	*Morone mississippensis*	Native	Other	C	Large	Other
Striped bass	*Morone saxatilis*	Native	Other	C	Large	Other
Sunfish	Centrarchidae					
Rock bass	*Ambloplites rupestris*	Native	Other	C	Other	Other
Green sunfish	*Lepomis cyanellus*	Native	Tolerant	I	Other	Other
Warmouth	*Lepomis gulosus*	Native	Other	C	Other	Other
Orangespotted sunfish	*Lepomis humilis*	Native	Other	I	Other	Other
Bluegill	*Lepomis macrochirus*	Native	Other	I	Other	Other
Redear sunfish	*Lepomis microlophus*	Native	Other	I	Other	Other
Longear sunfish	*Lepomis megalotis*	Native	Intolerant	I	Other	Other
Bantam sunfish	*Lepomis symmetricus*	Native	Other	I	Other	Other
Smallmouth bass	*Micropterus dolomieu*	Native	Intolerant	C	Other	Other
Spotted bass	*Micropterus punctulatus*	Native	Other	C	Other	Other
Largemouth bass	*Micropterus salmoides*	Native	Other	C	Other	Other
White crappie	*Pomoxis annularis*	Native	Other	—	Other	Other
Black crappie	*Pomoxis nigromaculatus*	Native	Other	—	Other	Other

Appendix.—Continued.

Common name	Scientific name	Origin	Tolerance	Feeding	Habitat	Spawning
Perch	Percidae					
Western sand darter	*Ammocrypta clara*	Native	Intolerant	I	Large	SL
Eastern sand darter	*Ammocrypta pellucida*	Native	Intolerant	I	Large	SL
Mud darter	*Etheostoma asprigene*	Native	Other	I	Other	Other
Greenside darter	*Etheostoma blennioides*	Native	Intolerant	I	Other	Other
Rainbow darter	*Etheostoma caeruleum*	Native	Intolerant	I	Other	SL
Bluebreast darter	*Etheostoma camurum*	Native	Intolerant	I	Other	SL
Bluntnose darter	*Etheostoma chlorosoma*	Native	Other	I	Other	Other
Fantail darter	*Etheostoma flabellare*	Native	Other	I	Other	Other
Slugh darter	*Etheostoma gracile*	Native	Other	I	Other	Other
Harlequin darter	*Etheostoma histrio*	Native	Intolerant	I	Large	SL
Johnny darter	*Etheostoma nigrum*	Native	Other	I	Other	Other
Orangethroat darter	*Etheostoma specatbile*	Native	Other	I	Other	SL
Tippecanoe darter	*Etheostoma tippecanoe*	Native	Intolerant	I	Other	SL
Logperch	*Percina caprodes*	Native	Other	I	Other	SL
Channel darter	*Percina copelandi*	Native	Intolerant	I	Other	SL
Gilt darter	*Percina evides*	Native	Intolerant	I	Other	SL
Blackside darter	*Percina maculata*	Native	Other	I	Other	SL
Slenderhead darter	*Percina phoxocephala*	Native	Intolerant	I	Other	SL
Dusky darter	*Percina sciera*	Native	Other	I	Other	SL
River darter	*Percina shumardi*	Native	Intolerant	I	Large	SL
Sauger	*Sander canadense*	Native	Other	C	Large	SL
Walleye	*Sander vitreus*	Native	Other	C	Large	SL
Drum	Scianidae					
Freshwater drum	*Aplodinotus grunniens*	Native	Other	—	Large	Other

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JAMES R. GAMMON: THE WABASH RIVER MAN

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James R. Gammon has been in Indiana since 1961 as a faculty member in Biological Sciences at DePauw University. It is my pleasure to concoct a brief, but accurate, biography of Dr. Gammon. I interviewed Dr. Gammon in August 2006 to obtain the majority of information that follows. From 1967 to 1998, he surveyed the fish assemblages of the Wabash River, building an incredible volume of data that comprises one of few long term fish assemblage compilations. My involvement with Jim was initiated when Tom Lauer and I were fortunate enough to inherit the monitoring program on the Wabash River that Gammon signed with funding from Cinergy Corporation (previously PSI, now Duke Energy) and Eli Lilly, Inc.

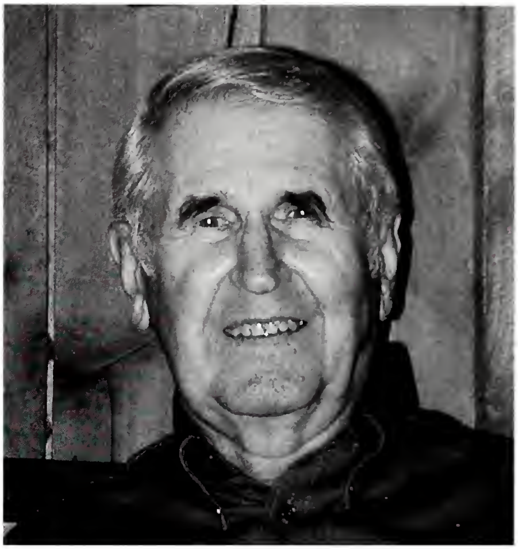

Figure 1.—James R. Gammon.

THE EARLY YEARS

James R. Gammon was born in Sparta, Wisconsin on 24 April 1930 to Abner James and Laverne Marie Robertson Gammon, and Jim had the honor of being the first member of his family to be born in a hospital. Dr. Gammon grew up in the nearby small village of Kendall, with his three siblings and his grandparents all sharing the same house. His father owned a family business, a combination dry goods and grocery store passed down from Jim's grandfather. Dr. Gammon's mother was a homemaker with organ and piano abilities. Jim's siblings have remained in the Midwest. His brother Dave has four daughters and lives in Wisconsin; his sister Barb has two children and lives in Illinois. Their youngest sister, Carol, has three sons and also lives in Wisconsin.

As a child, Jim always had an avid interest in science and nature, and he still retains those interests. He attributes this interest to his father and to his outdoorsman grandfather who lived with his family. They spent a great deal of time together in the woods where the grandfather and grandson fished and hunted. When he was six years old, Jim learned to shoot a .22 rifle and to catch brook trout in local streams. Together, he and his grandfather hunted squirrel, pheasant, and ruffed grouse (deer did not yet inhabit the southwestern Wisconsin driftless region). The Gammon family members were all interested in nature and always had many pets—mostly dogs and a few cats—and whatever stray or injured animal (including an owl and mink) they came across in the forest. Other summer activities included biking local rural roads and damming the local creek, a headwaters stream of the Baraboo River, for swimming. Winter activities included skiing and skating. Gammon's earliest jobs were working in his father's store, baling hay, working on a pea viner, and at the Standard "filling stations" where Gammon fixed hundreds of tires during World War II.

Jim developed a deeper, more scholarly interest in wildlife from books and *National Geographic* magazines he found in his grandmother's attic. Several of these books were texts discarded by his Uncle Wayne, who had attended college for a short period. Jim scanned his uncle's college chemistry text and realized he had in interest in chemistry. His parents then presented him with a chemistry set that Jim established in his basement, and he learned basic chemistry while burning holes in a few rugs.

Jim attended local schools in Kendall, Wisconsin. His high school had about 100 students, and Jim played basketball and baseball. His mother would not sign the paperwork to allow him to play six-man football until he weighed more than 130 pounds (he never got to play football!).

MILITARY SERVICE AND HIGHER EDUCATION

After graduating from high school Jim went to Waukesha, Wisconsin with a close friend, and they worked in a foundry. The boring, manual labor soon convinced them both to join the Navy, and they went through boot camp at the Great Lakes Naval Training Center. Jim remained stationed at the Great Lakes Center, went through Corps school, and spent the remainder of his active duty working in a pre- and post-surgery ward of the Mainside Hospital.

After serving in the Navy, Jim began college at the La Crosse State College, a school with perhaps 1000 students. The decision to attend La Crosse was easy since many friends from his hometown were also enrolled there. Jim describes these years as an enjoyable and memorable experience. He has fond memories of all of the basic courses, including biology and math. During the summer he again found work at a foundry in Milwaukee. The following fall the Korean conflict erupted, and Jim was drafted for service in the Navy for an additional two-year stint. The majority of this time was spent at the Great Lakes Naval Center.

Following his second military service, Jim transferred to the University of Wisconsin. He began a relationship with Carolyn Patricia O'Bierne who attended the UW–Whitewater campus, and they were soon married. They lived in Whitewater, and Jim took classes and graduated from UW–Whitewater in January 1956 with a BS degree. Jim has memories of many great people from this period, some of whom he still maintains close contact.

Following graduation from UW–Whitewater, Jim enrolled in graduate school at the UW–Madison with the goal of getting a teaching certificate to teach high school. He commuted from Whitewater because his wife Carolyn was still in school there. His professors convinced Jim to apply for further graduate training, and he was awarded a prestigious scholarship from the Danforth Foundation. Jim and his family subsequently moved to Madison, and Jim began five and a half years of graduate school. Dr. Arthur Hasler was Jim's major professor, and his major was in ecology. Hasler was famous for identifying the factors that salmon use in natal stream homing and for identifying cultural eutrophication of lakes as a potential crisis. Another well-known person at the UW with whom Jim worked closely was the eminent botanist Dr. John T. Curtis. Jim's graduate work was on muskellunge as predators to control panfish populations. The field work for this project was performed at the University of Wisconsin Trout Lake Station facility near Boulder Junction, Wisconsin (the site for the seminal limnological research of E.A. Birge and C. Juday). Jim earned a MS in 1957 and the Ph.D. in 1961 from the University of Wisconsin.

Jim interviewed for several faculty positions around the country but selected DePauw University in Greencastle, Indiana because he wanted a position where he could teach and yet maintain an active research program. At that time, most small teaching colleges strongly discouraged research by faculty. Jim also did not like the atmosphere of a research university, so Depauw University was a good fit. Jim and Pat produced an additional two children after settling in Greencastle (the previous two children were born during Jim's graduate career). Jim's second marriage was to Sherry Garner, who brought two children, Bradley and Shannon, into the family. Sherry was employed at DePauw University until she retired in 2004.

TEACHING AND RESEARCH AT DEPAUW UNIVERSITY

The courses that Jim taught at DePauw University included Comparative Vertebrate Anatomy, Vertebrate Biology, Ecology, Human Ecology for non-majors, Biostatistics, Introductory Zoology for non-majors, and Limnology. DePauw University had a graduate

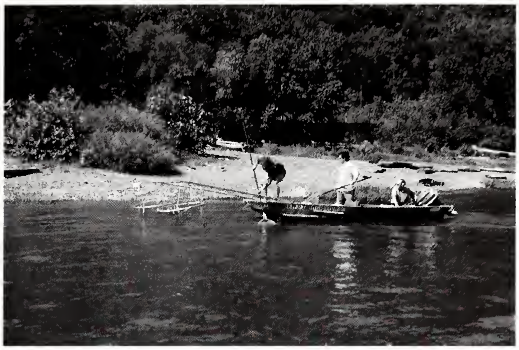

Figure 2.—Dr. Jim Gammon driving the boat electrofisher, and two student assistants netting fishes.

program when Jim was hired, and he graduated at least 24 master's degree students. The majority of Jim's students were involved in research on the Wabash River and the Ohio River, studying the effects of generation of electricity on fishes, macroinvertebrates, algae, and aquatic plants. Thus, an obvious and strong research interest was the Wabash River ecosystem, which was nearby to Greencastle. Other funded projects that Gammon managed included the effects of agriculture and inorganic sediments on fishes. The fish community ecology work resulted in the most obvious effects of electricity generating plants and thus had the most interest for Gammon and students. Additional research projects that Gammon pursued included topics as diverse as population ecology of fishes, toxicology, fish assemblages, thermal ecology, aquatic plants, macroinvertebrate ecology, and phytoplankton. His research interests were wide and included natural history studies of terrestrial and aquatic organisms. Associated activities with students included field trips to the Smoky Mountains during spring breaks, many winter term trips (including studies of coral reefs) to Andros Island, Bahamas and Baja California, Mexico, and canoe excursions to the Everglades National Park, Florida, and the Boundary Waters Canoe areas in Canada.

While Gammon was at DePauw he undertook many projects, resulting in dozens of reports and at least 64 publications including 28 peer-reviewed articles, reports, edited chapters in texts, and one textbook that summarized 30 years of sampling in the Wabash River (Gammon 1998). Gammon's earliest Indiana publication was written in conjunction with Shelby Gerking in *Natural Features of Indiana*. (A brief list of some publications is appended.) Jim currently has numerous manuscripts in progress or submitted for publication. His career is far from over!

A quote from Gammon's (1998) text on the Wabash River ecosystem provides a view of the humanistic interest of Gammon in studying the river:

> "Rivers, together with mountains, lakes, and oceans, are among the few natural features which bestow a permanence to an otherwise transitory world. There is something satisfying in the thought that a familiar nearby river once floated a birchbark canoe and will continue to be a source of enjoyment to our children and grandchildren."

One of the most impressive results of Gammon's research activities was the creation of the first multimetric index to score fish assemblage quality. Gammon's index of well-being (Iwb) was the precursor to the Index of Biotic Integrity (IBI) multimetric index that currently is used throughout the world in ecosystem assessment. Gammon's Iwb is a score that combines two indices of diversity (Shannon-Weiner diversity scores for abundance and weight) and two suitable weighted indices of abundance into a single number. The index was created as a method for simplifying data to a single number that would reflect the biotic integrity of the community (Gammon 1998). The immediate need at the time was for an index that the electric power industry might use to compare fish assemblages upstream and downstream from generation facilities to test for similar abundance and diversity.

Gammon was involved in many local organizations including Friends of Sugar Creek and Friends of the White River; and he was on the board for The Nature Conservancy for years. Gammon was active in numerous professional organizations including the Indiana Academy of Science (President in 1996), the Natural Areas Association, American Fisheries Society, the Society for Environmental Toxicology and Contamination, and the American Society for Limnology and Oceanography. Local and national newspaper reporters have interviewed him frequently for his environmental knowledge related to the Wabash River and agricultural pollution in Indiana

Figure 3.—Dr. Gammon in the field with students.

streams. Gammon was named the 2000 Environmentalist of the Year by IPALCO, the parent company of Indianapolis Power & Light Company. He became a Fellow of the Indiana Academy of Science in 1968.

STUDENT GUIDANCE

Gammon was a mentor to a huge number of undergraduate and graduate students during his career at DePauw University. Gammon's advice to students is to "try to aim for a career that you would do without being paid." A personal philosophy would include to "work hard and enjoy life." Past students include many who are currently in the public eye: Lee Bridges, Chris Yoder, John Riggs, Jerry Rud and Neil Parke. The following is a list of former students of Gammon, and the list includes the Master's thesis titles, year, and current locations where known:

Ujjal Tej Singh Deol. 1967. The effect of inorganic pollution on macroinvertebrate populations.

Robert S. Benda. 1967. The fish populations of Big Walnut Creek. (currently Professor of Biology, Department of Biology, Prince William Sound Community College, Valdez, Alaska)

Susan C. Bell. 1969. The effects of thermal pollution on the macroinvertebrate population of the Wabash River.

Randal A. Gaseor. 1971. The effect of temperature on the feeding rate and behavior of the caddisfly *Hydropsyche frisoni*.

Russell Scott Norris. 1972. The effect of heated water effluent on aquatic biota of Little Three Mile Creek. (currently a dentist in Mount Vernon, Indiana)

Jay T. Hatch. 1973. The responses of fish fauna of Little Three-Mile Creek and the Ohio River to a thermal effluent. (currently Associate Professor of Biological

Sciences, Dept. of Biological Sciences, University of Minnesota)

Steven T. Pierce. 1973. The effects of thermal enrichment on the macroinvertebrate populations of the Wabash River.

Lee Bridges. 1974. A study of the effects of the Newport Army Ammunition Plant upon the benthic fauna of Little Raccoon Creek and Little Vermillion Creek (Vermillion County, Indiana). (currently at Indiana Dept. of Environmental Management, Indianapolis, Indiana)

James R. King. 1974. A study of power plant entrainment effects on the drifting macroinvertebrates of the Wabash River.

A.P. Lesniak. 1974. The effects of the J.M. Stuart Station on fish of Little Three-Mile Creek and the Ohio River.

Eugene R. Mancini. 1974. Macroinvertebrate drift of the Wabash River and its relation to Wabash Generating Station (Terre Haute, Indiana). (retired from Atlantic Richfield Co., formed own consulting company doing Superfund and ecotoxicology studies)

Terry C. Teppen. 1975. Distribution and abundance of fish populations in the Middle Wabash River.

Brandon Kulik. 1977. The abundance and distribution of fish in the Ohio River in the vicinity of the J.M. Stuart Station: 1970 through 1976. (currently Senior Fisheries Biologist with Kleinschmidt Associates, Pittsfield, Maine)

Richard H. Wright. 1978. The distribution of fishes in southwestern Indiana.

William L. Fisher. 1979. An assessment of the fish populations of Eagle, Stotts, and Rattlesnake creeks in central Indiana. (currently at Cooperative Fisheries Unit, Oklahoma State University, Stillwater, Oklahoma)

Joseph M. Reidy. 1979. The role of tributaries in the recovery of a river from stress. (currently a lawyer in Columbus, Ohio)

E.M. Rogellin. 1979. The role of seining in the analysis of the Middle Wabash River.

Jerome L. Rud. 1982. The diets and interspecific relationships of twelve species of game fish from the Middle Wabash River, west-central Indiana. (currently at Indiana Dept. of Environmental Management)

David S. White. 1983. Effects of sediments on aquatic organisms. (currently Professor of Biology and Director of the Hancock Biological Station, Murray State University, Murray, Kentucky)

Edward S. Snizek. 1984. An evaluation of riparian forest and fish communities in an agricultural watershed.

Neil Parke. 1985. An investigation on phytoplankton sedimentation in the Middle Wabash River. (currently at Eli Lilly & Co., Indianapolis, Indiana)

Chris O. Yoder. 1976. Ohio River fish communities. (currently Director of Midwest Biodiversity Institute and Center for Applied Bioassessment and Biocriteria, Columbus, Ohio)

Lee Bridges mentioned that Gammon's editorial advice to students was to avoid Gammon's mistake: a draft of Gammon's dissertation included a sentence that was intended to explain the source of muskellunge gonads that were collected by native American guides. However, the first draft implied that the guides removed their own gonads. Bridges has many memories of river collecting trips where equipment failures prompted alternative operating techniques that were not safe or smart. But the net result was completed field work.

Gammon had an early "mini-computer" called a Wang. Because Gammon was the only person with the ability to write the code, he was the primary user of the computer. When DePauw University acquired mainframe computers, Gammon brought his computer to the university technicians with the hope of transferring data. The only help the technical staff could offer was "Wow, that's neat." Bridges mentioned that Gammon had an ongoing love affair with Saab automobiles, purchased from a dealership in tiny Perrysville. One of the more memorable vehicles was a two-stroke Saab station wagon that was replaced by other Saab sedans.

Gammon's son Bob assisted with Gammon's research projects for at least 10 years. Bob is currently working for a Cincinnati consulting firm funded by the U.S. EPA for training with hazardous waste. Bob worked on the Wabash River, the Ohio River, and local

Figure 4.—Jim Gammon is also an angler.

streams collecting fishes and water quality and habitat data. Bob has many memories of experiences in the field and of his father. He sums up his impressions of his father with the statement "I can't tell you how proud I am of him." Notable memories of his father include working on a nonpoint source EPA funded project on Stotts, Rattlesnake, and Eagle creeks near Zionsville in the 1970's. When the team visited one of the small tributaries of Eagle Creek to be sampled, they immediately noticed a chemical precipitate on the stream banks. Everybody scrambled for waders, and they sampled fishes with an electric seine and quantified the benthos and the habitat. It turned out that there was a hazardous waste site (Northside Landfill) immediately upstream. Gammon wrote the director of the Stream Pollution Control Board to complain about the stream condition. Subsequently, a landfill employee died while cleaning a toxic waste container. Jim Gammon was asked to testify about the condition of that stream at a local hearing; and, at the request of Gammon's wife, Bob went along to keep his father "safe." Gammon testified that the fish abundance was less than half of expectations and that the habitat was severely altered. Eventually the landfill was closed. Bob has proud memories of his father at that hearing and in other contexts as "fighting the good fight."

Bob Gammon described many of the sampling trips on the Wabash River as memorable. One notable memory was of sampling fishes near Darwin's Ferry at a time when local anglers were not catching catfish to their expectations. This was at the same time that another electrofishing crew had been sampling intensively in the same reaches. One fisherman pulled a rifle when Gammon's crew pulled up in view. Bob stated that "we took the hint and kept moving downstream." Other memories include boating down the river at full throttle between sites, and hitting an underwater log at such force that the motor flew off of the boat transom. Bob said that "everything was real quiet for a few moments" as the crew realized what had happened. They marked a tree on shore and returned with a sheriff rescue team to practice "dragging the bottom" to locate the missing motor. The motor was never found.

Chris Yoder recalls Gammon as "an extremely easy person to work for, and he was considered a colleague by all of his students." Gammon was very diligent in field work and attending conferences. Yoder says that Gammon ". . . set a good example for our conduct. Who knows what would have happened to a bunch of otherwise rowdy grad students on these forays." Gammon's nickname was "Chief," and Gammon was affectionately known among his students as the leader of "Gammon's Guerillas." Yoder considers Gammon's innovative designs of large river electrofishing gear and sampling to be the precursor and significant influence on all current large river fish sampling efforts.

IN "RETIREMENT"

Gammon retired from DePauw University in 1993 and currently has emeritus faculty status. Although Jim says that he is retired, he appears as busy as ever. For example, he serves on the White River Citizen Advisory Council and attends local conferences regularly.

ACKNOWLEDGMENTS

Jim Gammon was extremely helpful in generating this biography and locating other friends who provided information. I am grateful to Bob Gammon, Neil Parke, Chris Yoder, Lee Bridges, Brandon Kulik and many others for the interesting and lively stories about their colleague and mentor.

PARTIAL BIBLIOGRAPHY

1963. Conversion of food in young muskellunge. Transactions of the American Fisheries Society 92:183–184.

1965. The distribution of fishes in Putnam County, Indiana, and vicinity. Proceedings of the Indiana Academy of Science 74:353–359.

1965. Device for collecting eggs of muskellunge, northern pike and other scatter-spawning species. Progressive Fisheries Culturist 27:78.

1965. The effect of muskellunge on the resident fish populations of two bog lakes. Transactions of the Wisconsin Academy of Science, Arts and Letters 54:249-272. (with A.D. Hasler)

1965. The effect of pesticides on the bluegill *(Lepomis macrochirus)* in a northern Indiana lake. Proceedings of the Indiana Academy of Science 74:379–385. (with J.T. Hastings & M.J. Phelps)

1966. The fishes. Chap. 23. Pp. 401–425, *In* Natural Features of Indiana. (A.A. Lindsey, ed.) Indiana Academy of Science. 600 pp. (with S.D. Gerking)

1968. The fish populations of Big Walnut Creek. Proceedings of the Indiana Academy of Science 77:193–205. (with R.S. Benda)

1969. Determination of feeding rates in Trichoptera using ^{60}CO. Progress in Terrestrial and Freshwater Ecology. Publication No. 320, ORNL-4446:123–125.

1970. Aquatic life survey of the Wabash River, with special reference to the effects of thermal effluents on populations of macroinvertebrates and fish: 1967–1969. Progress Report to Public Service Indiana. 65 pp.

1970. The effect of inorganic sediment on stream biota. Water Pollution Control Research Series 18050DWC12/70:1–141.

1971. The response of fish populations in the Wabash River to heated effluents. Proceedings of the 3rd National Symposium on Radioecology. Pp. 513–523.

1973. The effect of thermal inputs on the populations of fish and macroinvertebrates in the Wabash River. Purdue University Water Resources Research Center. Technical Report No. 32. 106 pp.

1973. Effects of altitude and atmospheric windows on remote measurements of thermal effluent in the Wabash River. Proceedings of the 1st Pan-American Symposium on Remote Sensing. Pp. 147–159. (with L.A. Bartoluccci & R.M. Hoffer)

1975. Distribution and abundance of fish populations in the middle Wabash River. Thermal Ecology II (ERDA Symposium Series) CONF-75045: 272–283. (with T.C. Teppen)

1975. Seasonal distribution and abundance of Ohio River fishes at the J.M. Stuart Electric Generating Station. Thermal Ecology II (ERDA Symposium Series) CONF-750245: 284–295. (with C.O. Yoder)

1976. Measurement of entrainment and predictions of impact in the Wabash and Ohio rivers. Pp. 159–176, *In* Third National Workshop on Entrainment and Impingement. (L.D. Jensen, ed.)

1976. The fish populations of the middle 340 km of the Wabash River. Purdue University Water Resources Research Center. Technical Report No. 86. 73 pp.

1976. Recent collections of *Anepeorus simplex* (Walsh) (Ephemeroptera: Heptageniidae) from the Wabash River, Indiana. Entomological News

87:788:237–238. (with E.R. Mancini & P.H. Carlson)

1977. The status of Indiana streams and fish from 1800 to 1900. Proceedings of the Indiana Academy of Science 86:209–216.

1977. The effect of suspended solids on macroinvertebrate drift in an Indiana Creek. Proceedings of the Indiana Academy of Science 86:182–188. (with D.S. White)

1979. The role of electrofishing in assessing environmental quality of the Wabash River. ASTM Symposium Ecological Assessment of Effluent Impacts on Communities of Indigenous Aquatic Organisms. Pp. 307–324. (with A. Spacie, J.L. Hamelink & R.L. Kaesler)

1979. Development of a proposed list of endangered and threatened vertebrate animals for Indiana. Proceedings of the Indiana Academy of Science 88:166–170. (with H.E. McReynolds & J.O. Whitaker, Jr.)

1980. The use of community parameters derived from electrofishing catches of river fish as indicators of environmental quality. EPA Seminar on Water Quality Management Tradeoffs—Point Source vs. Diffuse Source Pollution: EPA-905/9-80-009. Pp. 335–363.

1981. The role of tributaries during an episode of low dissolved oxygen in the Wabash River. American Fisheries Society Warmwater Streams Symposium (Pp. 396–407). (with J.M. Reidy).

1981. The implications of rotenone eradication on the fish community of Eagle Creek in Central Indiana. Proceedings of the Indiana Academy of Science 90:208–215. (with W.L. Fisher)

1981. Biological Monitoring Program. Pp. 39–54, *In* Insights into Water Quality, Indiana Heartland Model Implementation Project, Status Report, March 1981. (with M.D. Johnson & C.E. Mays)

1982. Biological Studies. Pp. 1–25, *In* Insights into Water Quality, Indiana Heartland Model Implementation Project, Final Report, January 1982. (with M.D. Johnson, C.E. Mays, D.A. Schiappa, W.L. Fisher & B.L. Pearman)

1982. Effects of Agriculture on Stream Fauna in Central Indiana. EPA Report No. EPA-600/3-83-020. 88 pp. (with M.D. Johnson, C.E. Mays, D.A. Schiappa, W.L. Fisher & B.L. Pearman)

1982. The fish populations of Eagle, Stotts, and Rattlesnake creeks. Proceedings of the Indiana Academy of Science 91:171–182. (with W.L. Fisher)

1982. Changes in the fish community of the Wabash River following power plant start-up: Projected and Observed. ASTM, 6th Symposium on Aquatic Toxicology. Pp. 350–366.

1983. The fish communities of Big Vermilion River and Sugar Creek. Proceedings of the Indiana Academy of Science 92:183–190. (with J.R. Riggs)

1986. Sperm production and spawning success in muskellunge and northern pike. Pp. 87–92, *In* Biology and Management of the Muskellunge. (G.E. Hall, ed.) American Fisheries Society Special Publication 15.

1986. An investigation of phytoplankton sedimentation in the Middle Wabash River. Proceedings of the Indiana Academy of Science 95:279–288. (with N.J. Parke)

1987. Longitudinal changes in fish assemblages and water quality in the Willamette River, Oregon. Transactions of the American Fisheries Society 116:196–209. (with R.M. Hughes)

1987. Fishes of Marion County. Proceedings of the Indiana Academy of Science 97:583–597. (with J.O. Whitaker, Jr. & D.W. Kingsley).

1988. Endangered and Threatened Vertebrate Animals of Indiana. Monograph No. 5, Indiana Academy of Science. 122 pp. (with J.O. Whitaker, Jr.)

1988. Regional applications of an index of biotic integrity for use in water resource management. Fisheries 13:12–20. (with D.L. Miller, P.M. Leonard, R.M. Hughes, J.R. Karr, P.B. Moyle, L.H. Schrader, B.A. Thompson. R.A. Daniels, K.D. Fausch, G.A. Fitzhugh, D.B. Halliwell, P.L. Angermeier & D.J. Orth)

1990. Landuse influence on fish communities in central Indiana streams. Proceedings of the 1990 Midwest Pollution Control Biologists Meeting. Pp. 111–120. (with C.W. Gammon & M.K. Schmid)

1990. Fish communities and habitat of the Eel River in relation to agriculture. A Report for the Indiana Department of Environmental Management, Office of Water Management. 74 pp. (with C.W. Gammon)

1991. The fish communities of Sugar Creek. Proceedings of the Indiana Academy of Science 99: 141–155. (with C.W. Gammon & C.E. Tucker)

1991. Agricultural impacts on the fishes of the Eel River, Indiana. Pp. 85–99, *In* 1992. Proceedings of the 1991 Midwest Pollution Control Biologists Meeting: Environmental Indicators: Measurement and Assessment Endpoints. (T.P. Simon & W.S. Davis, eds.) U.S. EPA, Region V, Environmental Science Div.ision, Chicago, Illinois. EPA 905/R-92/003. (with C.W. Gammon)

1991. Biological monitoring in the Wabash River and its tributaries. Pp. 105–112, *In* Water Quality Standards for the 21st Century. (G. Flock, ed.) Office of Water, U.S. EPA. 251 pp.

1993. Changes in the fish community of the Eel River resulting from agriculture. Proceedings of the Indiana Academy of Science 102:67–82. (with C.W. Gammon)

1993. Environmental assessment of fish populations of the Wabash River and its tributaries. Natural Areas Journal 15:259–266.

1993. The Wabash River: Progress and promise. Pp. 142–161, *In* Restoration Planning for the Rivers of the Mississippi River Ecosystem. (L.W. Hesse, C.B. Stalnaker, N.G. Benson & J.R. Zuboy, eds.), U.S. Dept. of the Interior, National Biological Survey, Washington, D.C., Biological Report 19.

1994. The status of riparian wetlands in west-central Indiana streams. Proceedings of the Indiana Academy of Science 103:195–213.

1995. Environmental assessment and fish populations of the Wabash River and its tributaries. Natural Areas Journal 15:259–266.

1997. The Fishes. Pp. 310–317, *In* Indiana—A Natural Perspective. (M. Jackson, ed.) Indiana University Press, Bloomington, Indiana.

1998. The Wabash River Ecosystem. Indiana University Press, Bloomington, Indiana. 240 pp.

2000. Causes of variation in a great river index of biotic integrity over a 20 year period. Hydrobiologia 422/423:299–304. (with T.P. Simon)

2002. Patterns of water quality and fish assemblages in three central Indiana streams with emphasis on animal feed lot operations. Chapter 20, Pp. 373–417, *In* Biological Response Signatures: Indicator Patterns Using Aquatic Communities (T.P. Simon, ed.). (with W.C. Faatz & T.P. Simon).

2006. Stability of the fish assemblages of the Wabash River from 1974–1998. Freshwater Biology (51:1789–1797; with M. Pyron & T.E. Lauer)

Manuscript received 8 August 2006.

2006. Proceedings of the Indiana Academy of Science 115(2):196–198

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Walter, J. 1992. The significance and complexity of communication in moths. Pp. 25–66, *In* Insect Communications: Mechanisms And Ecological Significance. (P.N. Work & J.S. Rivers, eds.). Princeton University Press, Princeton, New Jersey.

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